NASA Technical Memorandum 4032

Modifications to the Langley 8-Foot Transonic Pressure Tunnel for the Laminar Flow Control Experiment

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MAY 1988

NASA

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National Aeronautics
and Space Administration

Scientific and Technical
Information Division

1988

Summary

Modifications to the NASA Langley 8-Foot Transonic Pressure Tunnel in support of the Laminar Flow Control (LFC) Experiment on a 7.07-ft, 23° swept supercritical airfoil included the installation of a honeycomb and five screens in the settling chamber upstream of the test section and a 54-ft-long contoured test section liner that extended from the upstream end of the test section contraction region, through the test section, and into the diffuser. The honeycomb and screens were installed as permanent additions to the facility, and the liner was a temporary addition to be removed at the conclusion of the LFC Experiment. This report briefly describes these modifications.

Introduction

In 1981, modifications were made to the NASA Langley 8-Foot Transonic Pressure Tunnel (8-ft TPT) in support of the Laminar Flow Control (LFC) Experiment on a 7.07-ft, 23° swept supercritical airfoil (ref. 1). Modifications included the installation of a honeycomb and five screens to improve the flow quality of the facility and a contoured test section liner to simulate unbounded flow about an infinitely yawed, large-chord airfoil model at transonic speeds. The honeycomb and screens, installed in the settling chamber upstream of the test section, were intended to be permanent additions to the facility. The 54-ft-long test section liner, which extended from the upstream end of the test section contraction region, through the test section, and into the diffuser, was a temporary addition to be removed at the conclusion of the LFC Experiment. The shape of the contoured liner conformed to the computed streamline flow field around the airfoil model at the design lift coefficient, Mach number, and Reynolds number. To prevent facility-generated pressure disturbances from feeding forward into the test section, an adjustable sonic throat consisting of two-dimensional, adjustable sonic choke plates located on the liner along opposing sidewalls was included as part of the liner design. These sonic choke devices were located about 1 chord length downstream of the trailing edge of the model, between the test section and the diffuser.

This report briefly describes these modifications. It is intended to serve as a consolidated source of reference for the permanently installed honeycomb and screens and as a guide during removal of the liner. Detailed installation procedures for the honeycomb and screens are contained in Specifications for Modifications to the 8-Foot Transonic Pressure Tunnel for Laminar Flow Control, Building 640, Specification No. 1-51-7106, as amended January 17, 1980. Fabrication and installation of the substructure of the test section liner are described in Specifications for Fabrication and Installation of Aero-Liner Sub-Structure for Laminar Flow Control, Building 640, Specification No. 1-52-7440, January 23, 1981. Mr. Nathaniel R. Spaulding and Mr. Gordon Owsley were Technical Project Engineers for the honeycomb and screens and the liner modifications, respectively.

About the same time that the honeycomb, screens, and test section liner were installed, the existing fan blade retaining boxes were replaced with new boxes constructed of AISI 4130 steel plate. The old boxes had been in use about 20 years and a number had developed cracks at the blade retaining pin holes. These cracks had been repaired to prevent the occurrence of more serious failures. Since the new boxes were designed to fit existing rotor hubs and fiberglass blades, there was little that could be modified dimensionally. However, close attention to metallurgy; heat treatment; stress relief; and minimization of stress concentrations by attention to fits, finish, and use of radii rather than sharp corners were expected to enhance the serviceability of the new boxes. These new boxes were considered replacements rather than modifications and are not further discussed in this report.

Symbols

c_l	airfoil section lift coefficient based on free-stream conditions
M_∞	free-stream Mach number
R_c	Reynolds number based on streamwise chord and free-stream conditions
R_{ft}	unit Reynolds number based on free-stream conditions
$\bar{u}$	mean value of velocity component parallel to centerline of tunnel
u'	root mean square value of velocity component

Abbreviations:

LFC	Laminar Flow Control
TPT	Transonic Pressure Tunnel
HST	High-Speed Tunnel

Tunnel With Conventional Test Section

The 8-Foot Transonic Pressure Tunnel (8-ft TPT) is a continuous flow, variable-pressure wind tunnel with controls that permit independent variations of

Mach number, stagnation pressure and temperature, and dew point. The exterior of the tunnel shell is covered with blown concrete insulation (sometimes referred to as gunite or shotcrete) for sound absorption. The normal test section is square with filleted corners and a cross-sectional area approximately equivalent to an 8-ft-diameter circle. The floor and the ceiling of the test section are axially slotted to permit continuous operation through the transonic speed range. The contraction ratio of the test section is 20:1.

A general layout of the tunnel is shown in figure 1. Figure 2 is a drawing of the test section showing the slots, windows, reentry flaps, diffuser flaps, and model angle-of-attack and support mechanism. Figure 3 shows photographs of the test section with the various components of the test section labeled. Figure 4(a) is a photograph of the turning vanes immediately downstream of the cooling coils as viewed upstream from the test section. When this photograph was taken, a vertical row of vanes down the center had been removed for access. Figures 4(b) and (c) show fairing plates that were installed to cover exposed bolt heads on the splitter plates to reduce disturbances in the test section.

Tunnel Modifications

Screens and Honeycomb

The general disturbance level measured (refs. 2 and 3) at the turning vanes upstream of the unmodified test section at a unit Reynolds number equivalent to the design Reynolds number of the Laminar Flow Control (LFC) Experiment ($R_{\mathrm{ft}} \approx 2.8 \times 10^6$) was $u'/\overline{u} \approx 8$ percent. In the settling chamber, downstream of the turning vanes, $u'/\overline{u}$ was approximately 2 percent. Predictions (refs. 4 and 5) indicated that to obtain the test section disturbance level required for laminar flow control experiments, 0.05 percent or less, at least five screens with pressure drops of 2.5 psf each were necessary. Research (ref. 6) had shown that screens of open-area ratios less than 0.57 tend to introduce instabilities and lateral disturbances. Much larger values, however, do not provide a sufficient drop in pressure to satisfactorily reduce axial disturbances. In evaluating the most effective combination of screens, several combinations of number of screens and mesh size were investigated (refs. 7 and 8) in a pilot tunnel at full-scale Reynolds numbers. These investigations, in conjunction with the geometry of the settling chamber, led to the choice of five 30 mesh, 304 stainless steel screens with open-area ratios of 0.65. Wire diameter was 0.0065 in.

Screens alone are not very effective for removing swirl and mean-lateral velocity variations. Research (refs. 9 and 10) had shown that a honeycomb with cell length at least six to eight times the cell diameter is preferable if the flow incidence does not exceed about 10°. The primary restriction on cell width is that it must be smaller than the smallest lateral wavelength of the variations in velocity. The resulting honeycomb geometry selected had an open area of 95 percent with cells 3/8 in. across (referred to as square cell honeycomb) and 3 1/2 in. deep. It was made of 304 stainless steel with 0.006-in. wall thickness and was designed for a pressure drop of 1.25 psf. Since the flow resistance coefficient of honeycomb material is usually about 0.5, small when compared with the flow resistance of screens, it was not expected to contribute appreciably to tunnel power requirements.

Modifications for improving flow quality, therefore, included the installation of a single-grid honeycomb unit and five screens in the settling chamber upstream of the test section and just downstream of the turning vanes. Table I is a summary of the general design criteria for the honeycomb and screens. All were installed perpendicular to the longitudinal axis of the tunnel. Figure 5 shows the location of the honeycomb and screens relative to the overall tunnel circuit, and figure 6 is a sketch of the general installation. The honeycomb was located as close as possible to the turning vanes, and the first screen was located 30 in. downstream of the honeycomb. The five screens were located on 12-in. centers.

Preliminary measurements have indicated that disturbance levels ($u'/\overline{u}$) of approximately 0.07 percent were achieved in the lined test section under choked flow conditions.

Because of the limited access and the extensive scaffolding required, it was necessary first to completely install the honeycomb and second to install the five screens, beginning with the most upstream screen (screen 1) and progressing downstream with the other four screens (screens 2–5). Fairings (fig. 7) around the perimeter of the honeycomb and screens (discussed later) to cover mounting hardware also were installed as installation of the honeycomb and screens progressed. These fairings were 10 in. deep, measured from the interior surface of tunnel to the windward surface of the fairings, making the exposed honeycomb and screen 34 ft, 4 in. in diameter.

Tunnel access. Because of limited access to the tunnel circuit where the honeycomb and screens were to be installed, it was necessary to remove some existing external overhead vacuum piping and valves (see fig. 8) between the 8-ft TPT and the nearby 8-ft High Speed Tunnel (no longer in operation) and to cut a temporary access hatch through the side of the tunnel (fig. 9). This hatch was located near the horizontal centerline of the tunnel immediately

downstream of the fifth screen. It was used to facilitate installation of the honeycomb panels, screens, and scaffolding, and to facilitate future access. A new permanent access hatch was installed through the bottom of the tunnel shell between the honeycomb and screens to allow access for inspection and cleaning.

Installation of honeycomb. The honeycomb was assembled in the tunnel from 104 precut and fitted panels, which were joined by welding along their edges to form a single, continuous grid unit. The maximum panel size was 1 by 12 ft and weighed about 50 lb. Welding was accomplished by using round, wheel-type electrodes on the end of two "fingers" which were inserted through the honeycomb (with the double wall thickness of a joint between the electrodes) and slowly withdrawn. The speed at which the electrodes were withdrawn and the timing of a pulse generator resulted in a uniform series of spot welds along the depth of the joints.

Before final assembly in the tunnel, however, the panels were cut, fitted, and assembled on the floor (fig. 10) at a remote assembly site. The outer perimeter of the assembled unit was cut to conform to the shape of the tunnel. Edges of individual panels were cut so that, when joined, edges of cells matched to ensure a continuous cell pattern across joints. This is illustrated in figure 11 where corners of four panels are shown joined together. Considerable care was taken to prevent damage, such as cell distortion and/or edge crimping, during installation.

The honeycomb was supported around its perimeter by clamping plates as shown in figure 12(a). Figure 12(b) shows the honeycomb support apparatus in relationship to the mounting apparatus for the five screens. The screen installation will be discussed in more detail in a later section, but figure 12(b) illustrates how the screens were supported by spring-tensioned cables through pulleys. Springs for the two most upstream screens were mounted on the honeycomb clamping-plate support (fig. 12(a)), and those for the three downstream screens were mounted on a spring support bracket downstream of the fifth screen (fig. 12(c)). Figure 12 also shows the fairing that covered the mounting hardware and streamlined the airflow around the edge of the honeycomb and screens. Photographs in figure 13 show various stages of the installation of the mounting hardware. Figures 13(a) and (b) are views of the screen pulleys and pulley brackets before and after portions of the screen fairing-plate supports were installed. Figure 13(c) shows later stages as installation progressed around the perimeter of the settling chamber.

Figure 13 also indicates the extensive scaffolding that was required. Particular attention is directed toward the unique rolling base of the scaffold, which permitted it to be rolled downstream as each phase of the installation was completed. Photographs showing the scaffolding in more detail are presented in figure 14.

Installation of the honeycomb required additional scaffolding on the upstream side to permit access to both sides of the honeycomb and to allow access to the compression springs for the first and second screens. This upstream scaffolding was constructed of wood (with metal brackets attached to the pressure shell) and is shown in the photographs of figure 15.

The general installation procedure for the honeycomb, after scaffolding had been erected on both sides of the honeycomb, began with shimming the first panel, which was a large panel near the centerline, to the proper location and hanging it from the top of the tunnel with clamping bolts. Figure 16(a) is a view from the floor of the tunnel during this early stage. After the first panel was in place, adjacent panels were brought in, aligned to match cell edges, and spot welded along their edges. As the panels were assembled, additional clamping plates were attached. This step-by-step procedure was repeated until all the panels were in place. Photographs presented in figure 16 show various stages of the honeycomb installation and also show the two-pronged welding probe in use. Figure 17 is a photograph showing screen tension cables to the first two screens and fairing plates between the installed honeycomb and the first screen location.

Since significant deflection of the honeycomb under its own weight or under air loads would be undesirable, a maximum allowable operating deflection of 0.3 in. was specified. Although the installed honeycomb structure was a rigid, self-supported structure, eight lateral support cables distributed over the upstream face of the honeycomb were attached to the turning vanes to provide additional longitudinal airload support. Each cable (see photograph, fig. 18) consisted of a central attachment wire with a six-wire yoke assembly to spread the load over the honeycomb. Tension in these cables was about 25 lb, enough to take up the slack, but not enough to exert upstream loads on the honeycomb. It may be noted that these support cables were designed when an aluminum honeycomb was being considered and the additional support was needed. When difficulty was encountered joining test panels of aluminum because of the melting and welding temperatures being so close together, the aluminum design was abandoned in favor of steel honeycomb material, but the support cables were retained for added safety.

Installation of screens. The screens were prefabricated to the required dimensions and included a perimeter hem with a 5/32-in. cable with provision for bolts every 1°. Installation specifications called for clevis pins, which connected the perimeter of the screens to the tension cables, to be installed every 3°, or in every third bolt hole. The hem of the screens, segmented strongback, and details of the clevis pins are shown in the sketches of figure 19. Figure 20 is a sketch of the screen supports for the fourth and fifth screens showing their relationship to the screens and clevis pins.

The screens were constructed of 18-ft-wide strips of screen material, and, to keep the seams away from the centerline of the test section, an 18-ft strip was placed down the center of each screen with brazed joints 9 ft off the centerline as shown in figure 21. Screen 1 was installed with the seams vertical. Each succeeding screen (screens 2 through 5) was installed with the seams rotated 72° such that there was a 10-sided seamless regular polygon in the center with an 18-ft diameter.

After fabrication, the screens were carefully and individually rolled between two polyethylene sheets onto a fiberglass tube. Each screen and tube was wrapped in polyethylene sheets and inserted into a cardboard box with a wooden support frame for delivery to the tunnel. Particular attention was paid to orientation of the brazed joints while rolling the screens onto the tube so that when the screen was unrolled in the tunnel, the joints would be properly oriented.

Figure 22 is a sketch of the truss-monorail system, constructed outside the tunnel, along which to slide the rolled screens through the temporary access hatch and into the tunnel. Figures 23(a) and (b) present photographs of the monorail (note that these photographs were taken after the temporary access hatch had been closed), and figure 23(c) shows the rolled up screens lying on the ground, parallel to the monorail, ready to be put into the tunnel.

Once a rolled up screen was inside the tunnel (fig. 24(a)), the top portion was partially unrolled and strongback segments were clamped to the perimeter with bolts in the hem bolt holes between clevis locations. (See fig. 19.) Temporary hoisting clamps then were attached to the strongback segments and in turn connected to hoist ropes that ran through temporary pulleys in the ceiling that were supported by J bolts (fig. 24(b)). The screen was slowly unwound with the hoist ropes (fig. 24(c)) until it reached the top of the tunnel, with more and more strongback segments and hoisting clamps added as the hem was exposed. Once the screen reached the top of the tunnel, the remainder of the screen was carefully unrolled and lowering ropes were attached to the perimeter cable. The bottom of the screen was then lowered until the screen hung vertically. Temporary restrainers were attached to the bottom half of the screen to prevent sway while the remainder of the screen strongbacks were attached. At this point, the staging was moved into position, and, beginning at the top, clevises and compression springs were attached around the perimeter of the screen. The springs were adjusted to center the screen in the tunnel and tightened in a specified sequence. During this phase of installation, it became necessary to enclose the compression springs in metal sleeves to prevent buckling (fig. 25).

When installation of the first screen was completed, fairing plates were installed and the J bolts and temporary pulleys were moved to the next upstream screen location.

After screens 1 and 2 were installed, cable assemblies were mounted on the spring support brackets downstream of screen 5 and screens 3, 4, and 5 were installed according to the procedures described above.

When all the screens and fairings around the mounting hardware were installed, the monorail and supports inside the tunnel were removed and stored, the interior surfaces of the tunnel were cleaned and smoothed, and all scaffolding was removed from the tunnel. The temporary access was closed with a hatch cover and a weather seal cover at the shotcrete opening. The exterior monorail trolleys and hoists were removed and stored. The photograph in figure 26 is an upstream view from the test section of the fifth screen after installation was completed.

Although referred to as a temporary access, the hole in the side of the tunnel can be reopened at a later time by removing the hatch cover.

Test Section Liner

Because of the blockage associated with the large, 7-ft-chord LFC model, the conventional slotted test section was reshaped with a four-wall contoured liner (fig. 27). The liner was designed without slots in order to reduce the acoustic disturbances associated with the slotted test section that is normally used to reduce the effects of blockage. The walls were contoured, not only to alleviate the blockage problem associated with large model size and to eliminate noise due to test section slots, but also to correct for the interference effects of the tunnel sidewall on the cross flow in the field about the swept model, i.e., alleviate model end effects. The 54-ft liner extended from the tunnel contraction region (24-ft station), through the test section, into the diffuser

(78-ft station). The 50-ft tunnel station in the liner coordinate system corresponded to the slot origin of the 8-ft TPT slotted test section.

The shape of the contoured liner conformed to the computed streamline flow field around the wing at the design conditions for the model ($M_\infty = 0.82$, $c_l = 0.47$, and $R_c = 20 \times 10^6$). To reduce costs, liner contours were fixed and followed the predicted undisturbed streamlines for only the one test condition. Reference 11 discusses the analytical design of the liner.

To prevent facility-generated pressure disturbances in the diffuser from feeding into the test section, the design of the liner included an adjustable sonic throat made of two-dimensional, adjustable sonic choke plates placed on the liner along opposing tunnel sidewalls. These sonic choke plates were located about 1 chord length downstream of the trailing edge of the model, between the test section and the diffuser (fig. 27).

The first step in the installation of the liner was to strip the existing test section down to the bare walls. The windows, slot edges, diffuser flaps, model sting support system, and corner fillets were removed and holes were burned in the floor and ceiling of the test section for model suction piping. Figure 28 shows photographs of the test section with the windows removed and the process of machining away the edges of the corner fillets so that they could be removed. The photographs in figure 28 are views taken from the test section access door looking toward the east and slightly upstream. Figure 29 shows photographs of some of the holes burned in the floor and the ceiling. Figure 30 shows the hardware on the floor of the storage area after being removed from the test section.

In general, the liner in the vicinity of the test section was attached to a temporary substructure made of metal plates or strips bolted to studs welded to the test section walls. Whenever possible, a stud welding gun was used to minimize the grinding required when the studs are removed. Conventional welding techniques were used in locations where use of the stud welding gun was not feasible. Figure 31 shows photographs of various stages and views of the substructure during installation. The outer surface of the liner was made of about 100 rigid foam blocks bonded to 3/4-in. plywood backing (fig. 32) and bolted to the substructure. Each foam block was numerically machined (fig. 33) to the proper contour before installation.

In several locations, supports for strut-mounted flow-measuring devices were embedded in the liner. Such supports were for the most part circular plates welded to pipes that projected through the test section walls into the plenum surrounding the test section. On the plenum side of the wall, metal rings were slipped around the pipe and welded to the pipe and to the wall.

In the entrance cone section of the tunnel, between the 24-ft and approximately 38-ft tunnel stations where the cross-sectional shape of the tunnel changes from round to square, the liner was so thick that plywood supports were used to build up the substructure on which the foam blocks rested. Figure 34 is a sketch of the substructure cross section in this region. Figure 35 presents photographs of various stages of construction in this region of the tunnel. Figure 35(a) shows the plywood supports behind the support beams welded to the walls of the tunnel at the 29-ft 8-in. station. Figure 35(b) shows several of the plywood supports in the test section before installation. Figure 35(c) shows support extensions that were welded around the perimeter of the support beams with one plywood plate installed in the lower right-hand corner. Figure 35(d) is a photograph taken during installation of the support extensions and plywood plates, and figure 35(e) is a photograph showing the installation of the plywood plates nearly completed.

Since it would have been difficult to machine the foam blocks to a sharp point at the leading edge of the liner (24-ft station), the foam blocks were stopped downstream of the leading edge, and aluminum leading-edge fairing plates, supported by wooden leading-edge fairing supports, were used to fair the liner into the tunnel wall. (See sketch in fig. 34.) A photograph showing the leading-edge fairing supports butted against the upstream edge of the foam blocks is shown in figure 36(a). Figure 36(b) shows a later phase of installation with a leading-edge fairing plate installed. A plastic curtain that was installed slightly upstream of the leading edge of the liner to act as a barrier and protect the screens from falling debris can be seen at the top of the photograph in figure 36(b). Figure 37 shows photographs during various stages of installation with scaffolding and the plastic curtain barrier in place. Figure 37(a) is a view looking upstream toward the floor of the settling chamber from the test section and shows a work platform used to work on the lower section of the liner leading edge. The other photographs in figure 37 are views looking downstream toward the test section from the floor of the settling chamber. Figure 38 is a photograph of a wooden barrier on the floor of the settling chamber; it provided added protection for the screens during installation of the liner. Figure 39 is a photograph of the completed entrance cone region with a foam block removed from

the floor to indicate the nature of the liner in that region.

Figure 40 contains photographs showing different views during various stages of installation of the foam blocks through the test section, beginning at the upstream end, progressing around the model wing box, around the choke plates, and into the diffuser behind the tunnel access door. To seal the small gap between the foam blocks, a wider channel was routed (fig. 41) in the surface along the joints and was filled and sanded flush with the surface.

To complete the liner and to fair the liner into the diffuser walls, metal fairing plates were installed on the ceiling and floor immediately downstream of the test section access door (fig. 42). Figure 42 also shows the wooden fillets in the corners downstream of the access door between the 70- and 78-ft tunnel stations.

Photographs of the completed test section liner are shown in figure 43.

Concluding Remarks

Modifications have been made to the NASA Langley 8-Foot Transonic Pressure Tunnel in support of the Laminar Flow Control (LFC) Experiment. These modifications included the installation of a honeycomb and five screens in the settling chamber upstream of the test section, and a 54-ft-long contoured test section liner that extended from the upstream end of the test section contraction region, through the test section, and into the diffuser. The honeycomb and screens were intended to be permanent additions to the facility, and the liner was a temporary addition that is to be removed at the conclusion of the LFC Experiment. This report briefly describes these modifications. It is intended to serve as a consolidated source of reference for the honeycomb and screens and as a guide during removal of the liner.

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March 29, 1988

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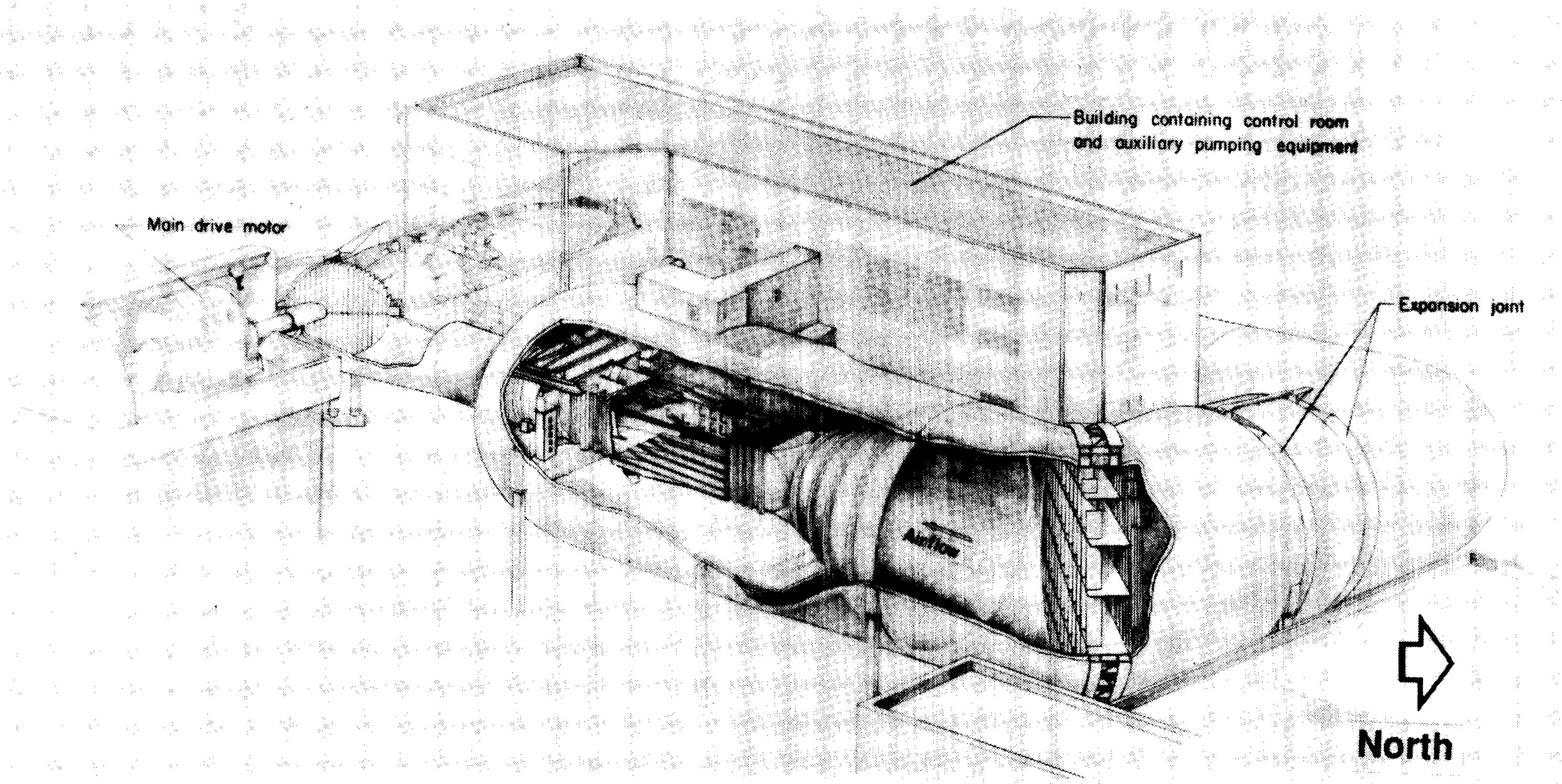
Table I. Design Criteria for Honeycomb and Screens

1. One honeycomb unit with 95-percent open area
   (a) 3/8 in. square cell, 3 1/2 in. deep
   (b) 304 stainless steel
   (c) 0.006-in. wall thickness
   (d) Maximum deflection 0.3 in.
2. Five screens with 65-percent open area
   (a) 30 mesh with 0.0065-in-diameter wire
   (b) 304 stainless steel
   (c) Maximum deflection 6 in.
3. Spacing
   (a) Honeycomb as close as possible to turning vanes
   (b) First screen 30 in. downstream of honeycomb
   (c) Five screens spaced 12 in. on center
4. Pressure drops
   (a) Honeycomb, 1.25 psf
   (b) Screens, 2.50 psf each
5. Access for inspection and cleaning



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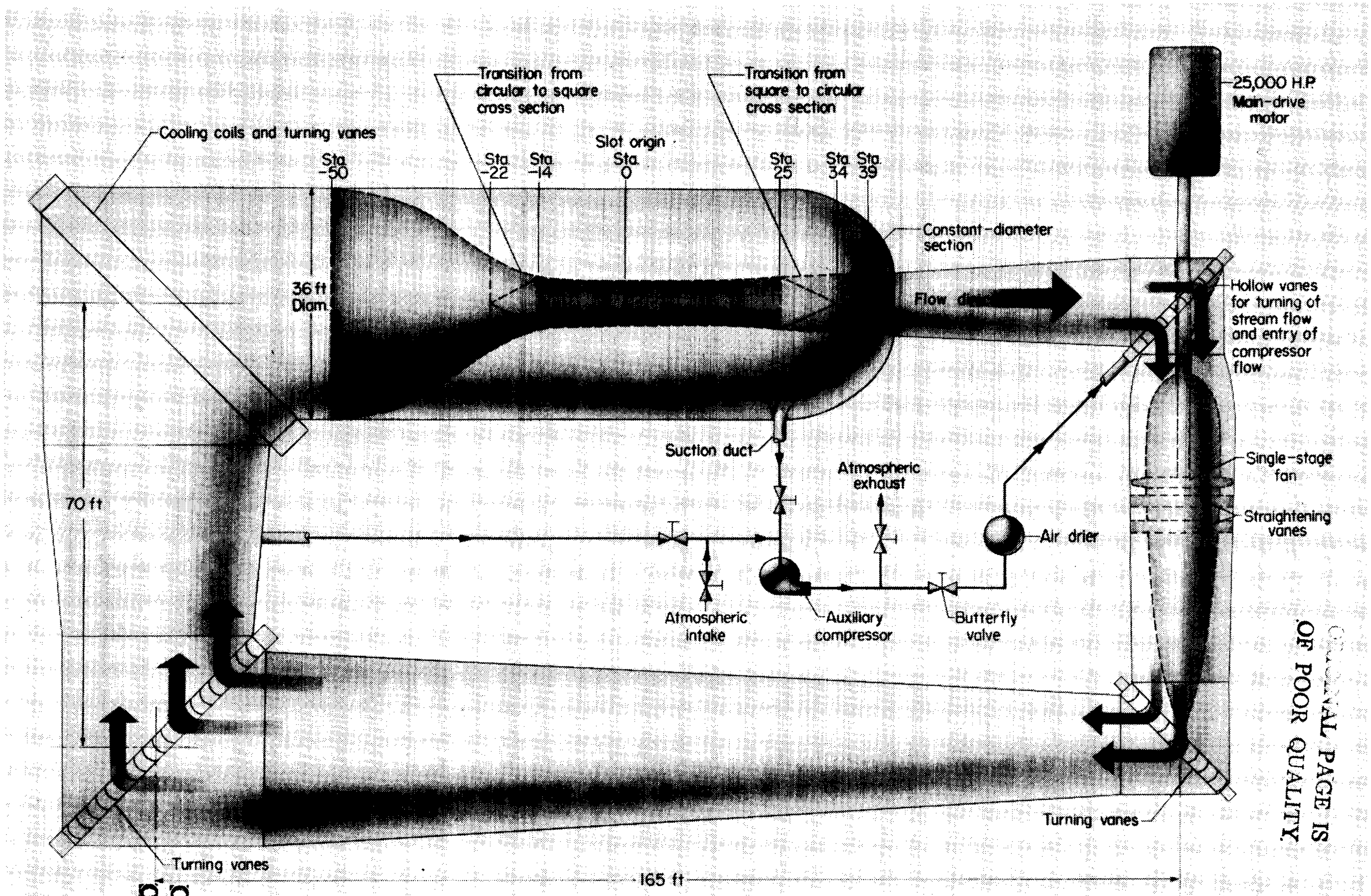
(a) Artist's conception.

Figure 1. 8-Foot Transonic Pressure Tunnel.



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(b) Plan view with auxiliary pumping circuit. Tunnel stations shown are in feet.

Figure 1. Concluded.

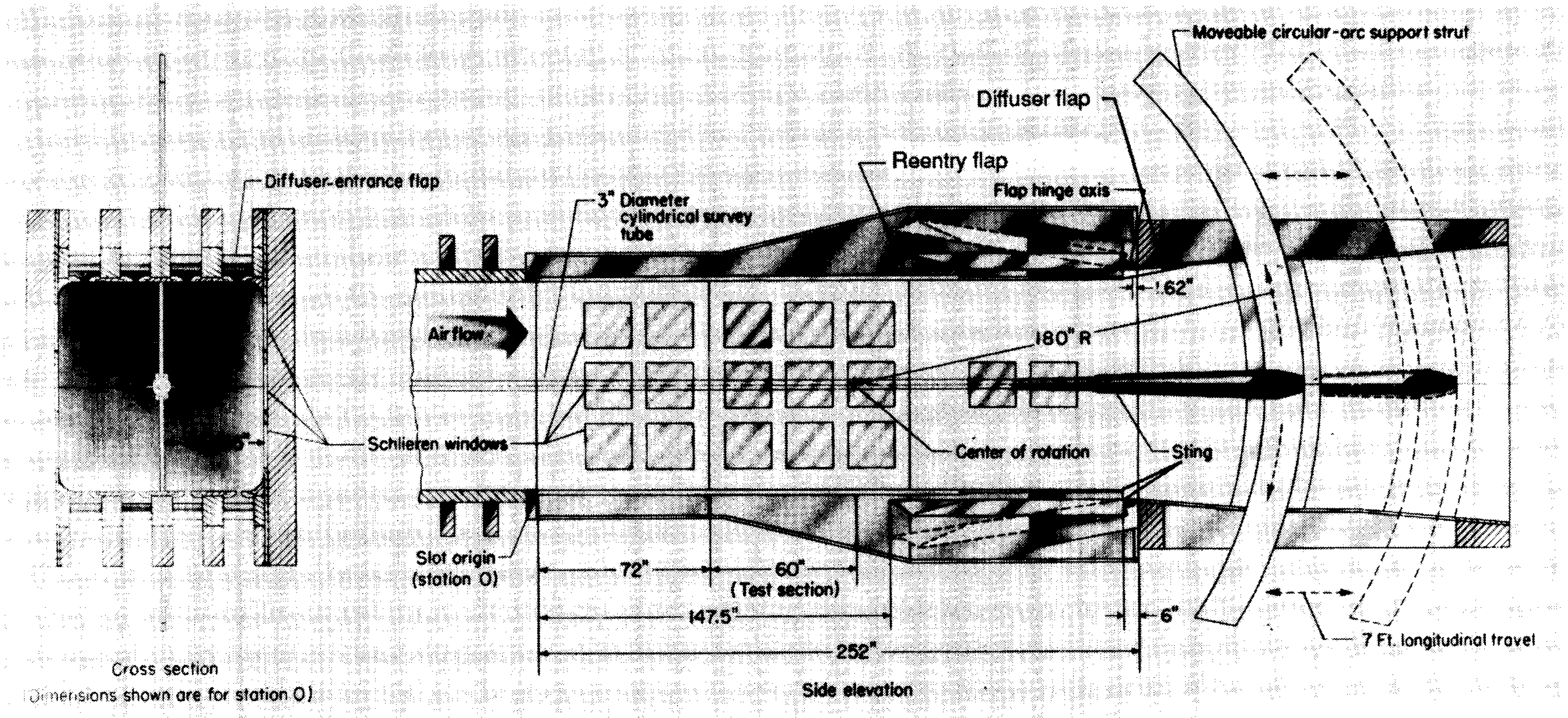

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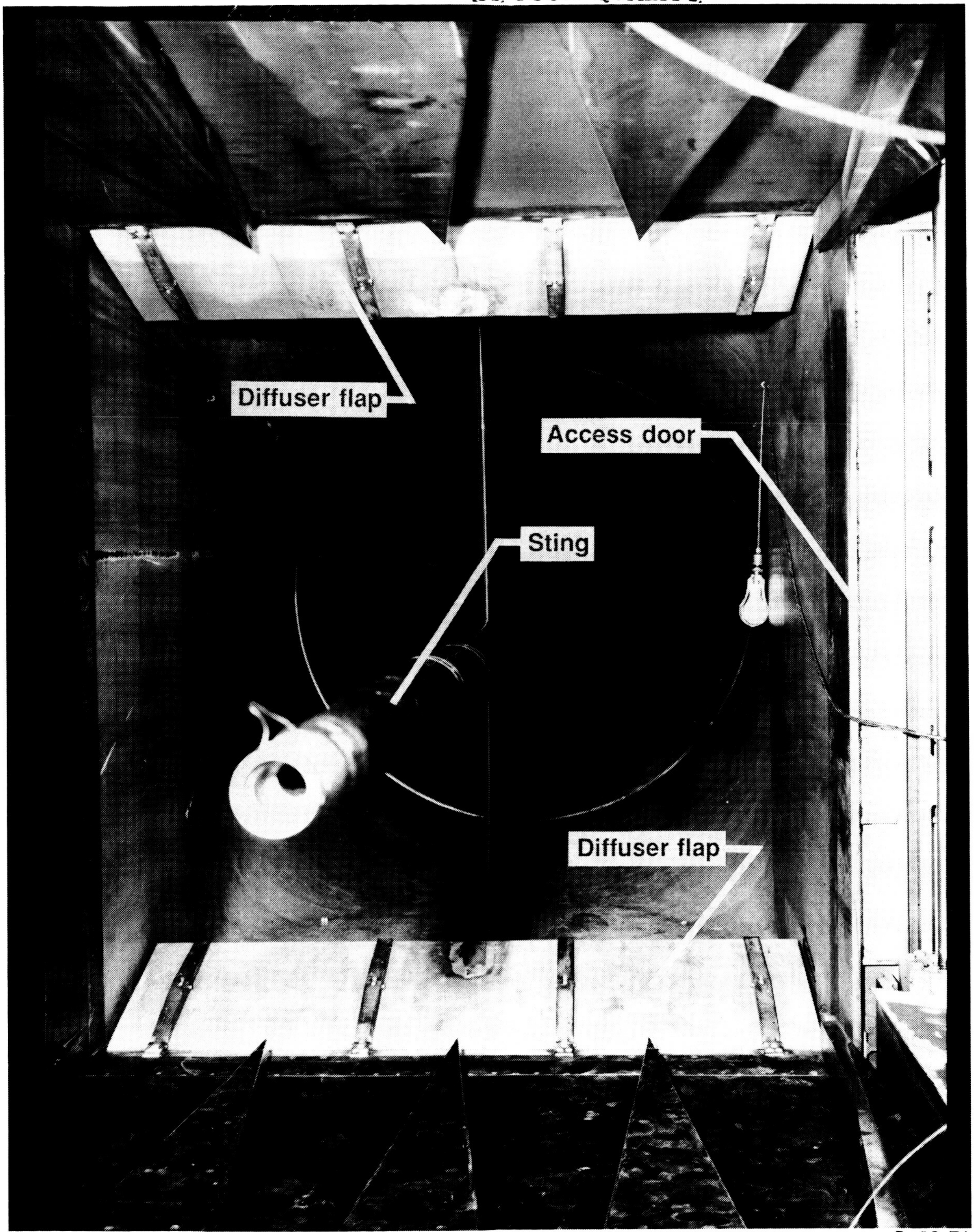
Figure 2. Slotted-throat and diffuser-entrance regions of the 8-ft TPT.



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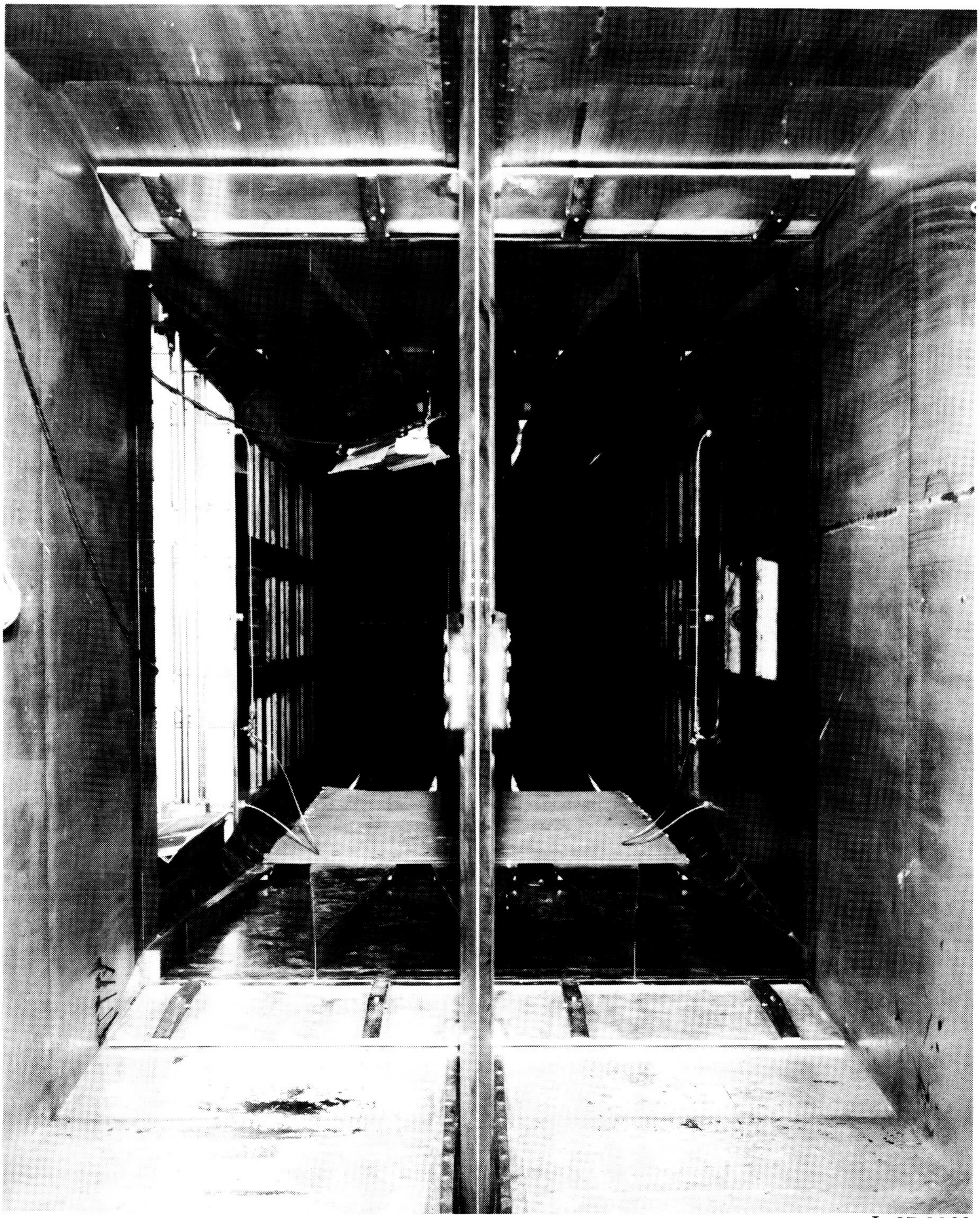
(a) Downstream view of diffuser from test section with diffuser flaps in extended position.

Figure 3. Photographs of conventional test section.



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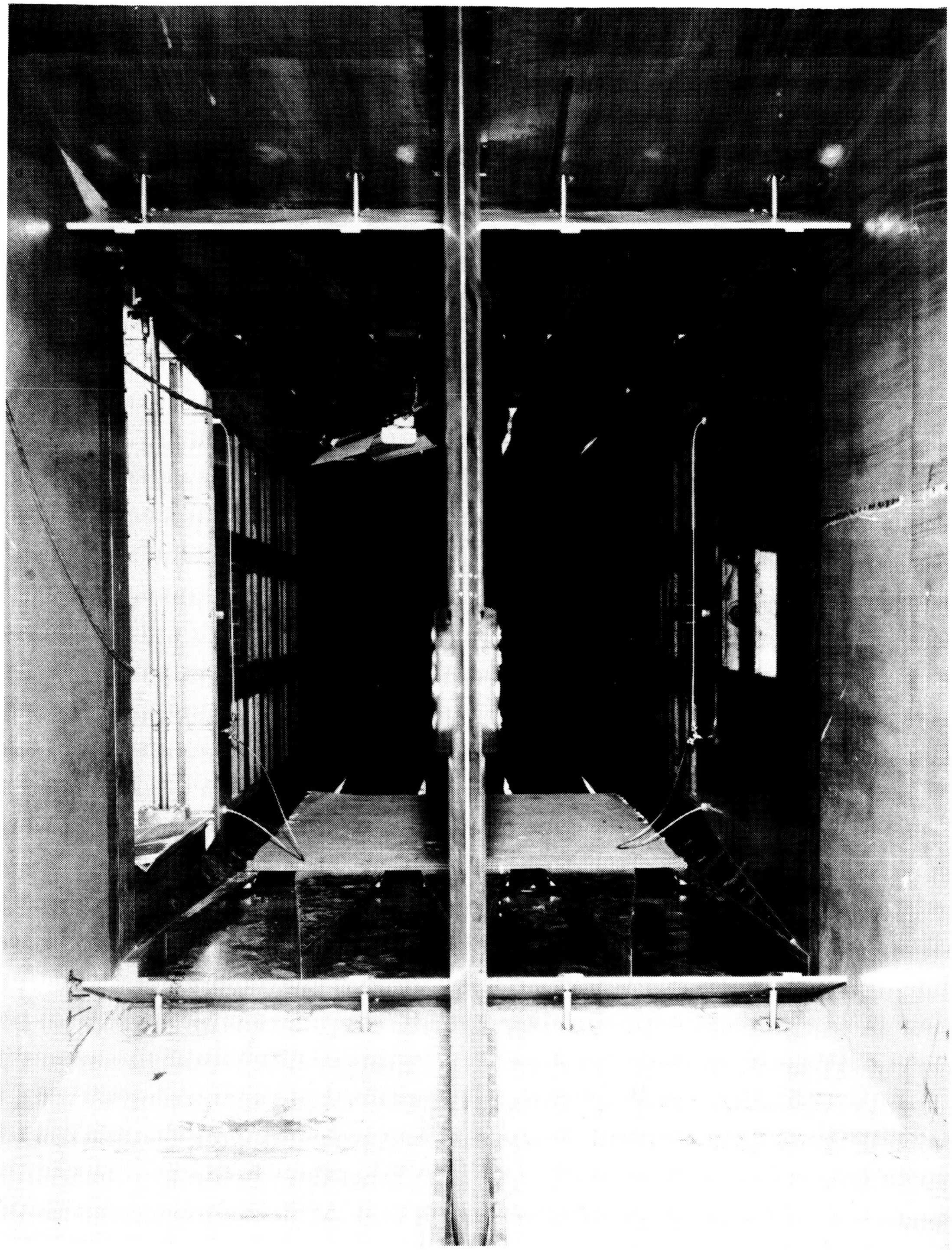
(b) Upstream view of test section from diffuser with diffuser flaps in retracted position.

Figure 3. Continued.



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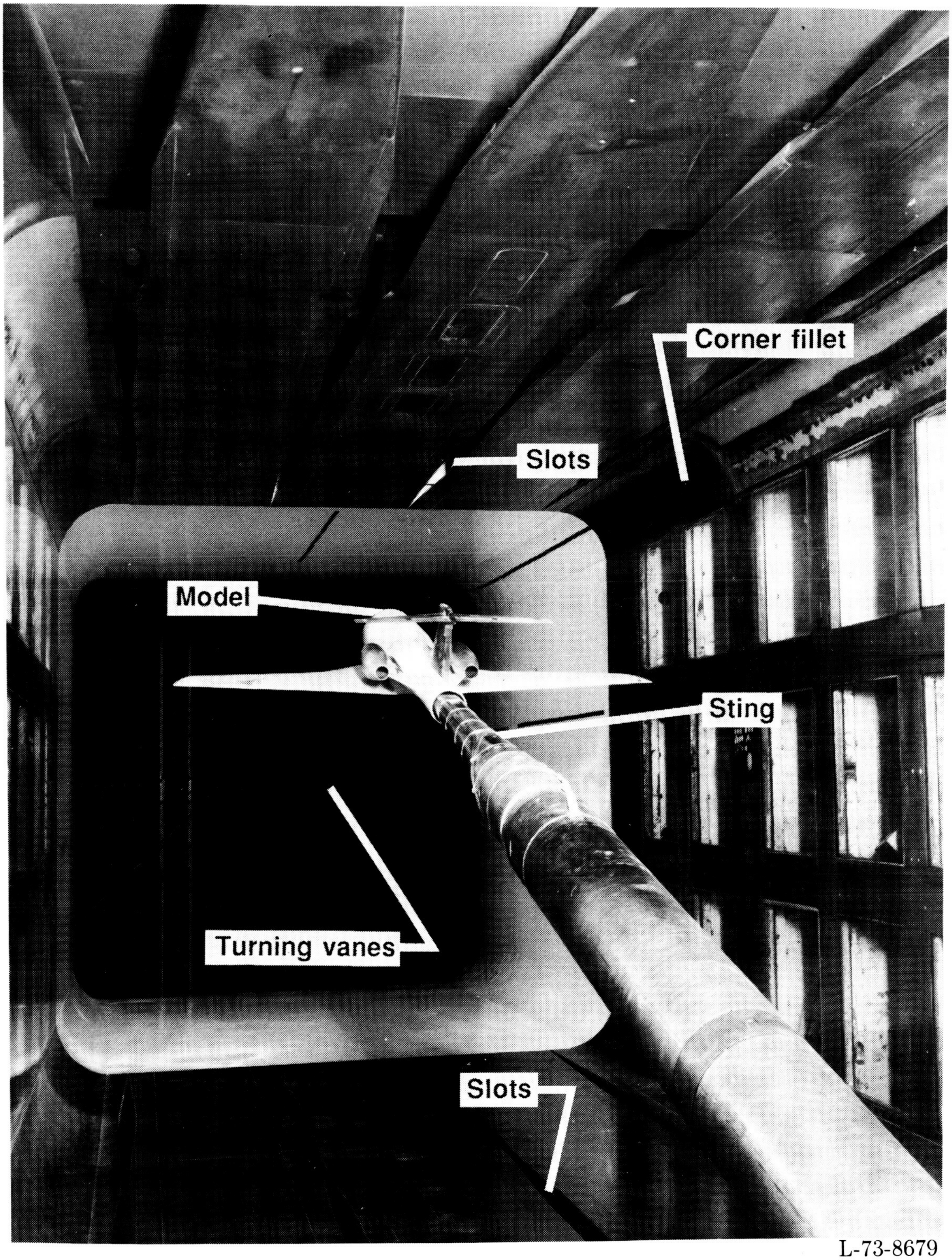
(c) Upstream view of test section from diffuser with diffuser flaps in extended position.

Figure 3. Continued.



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(d) Upstream view of test section with typical sting-mounted model installed.

Figure 3. Concluded.

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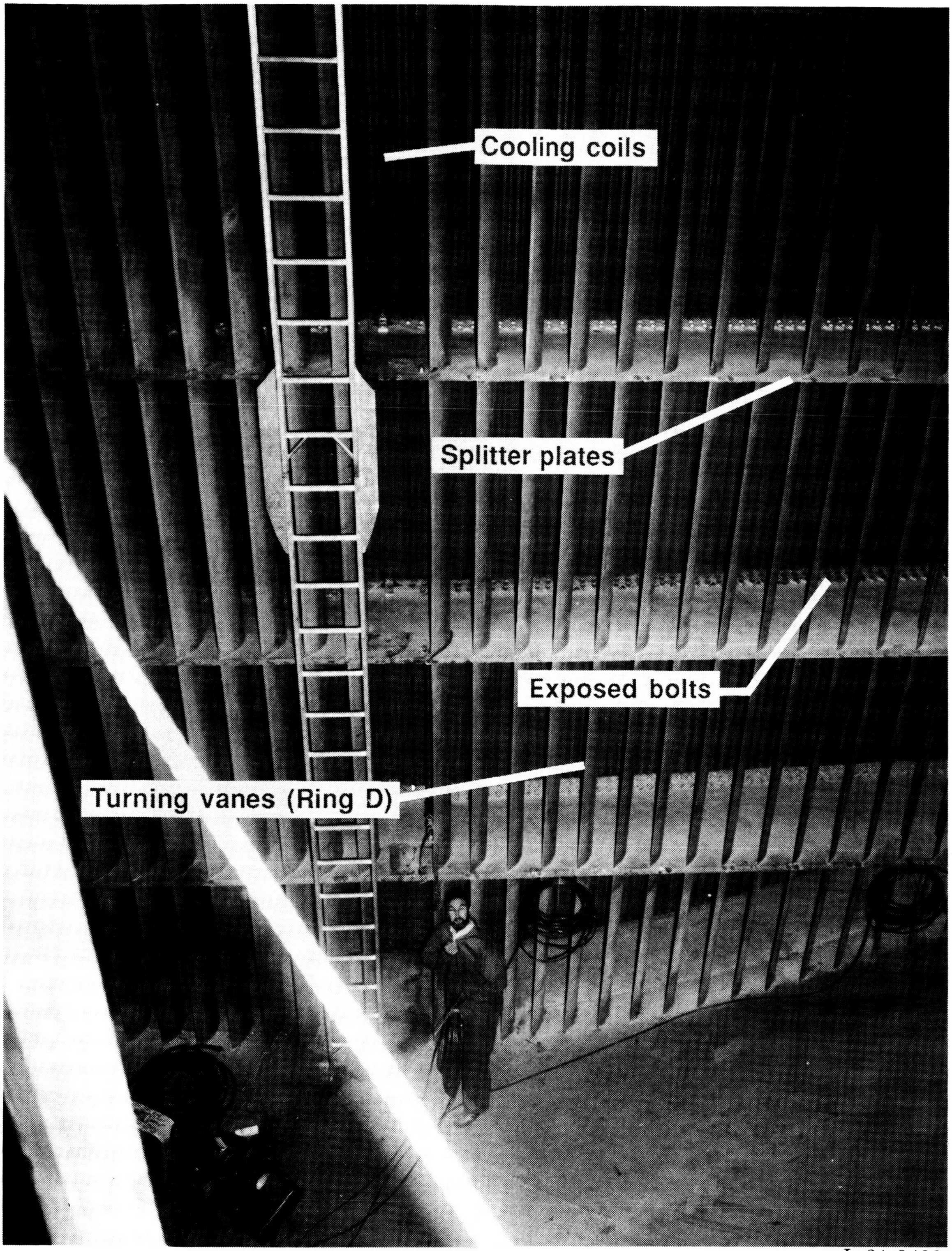

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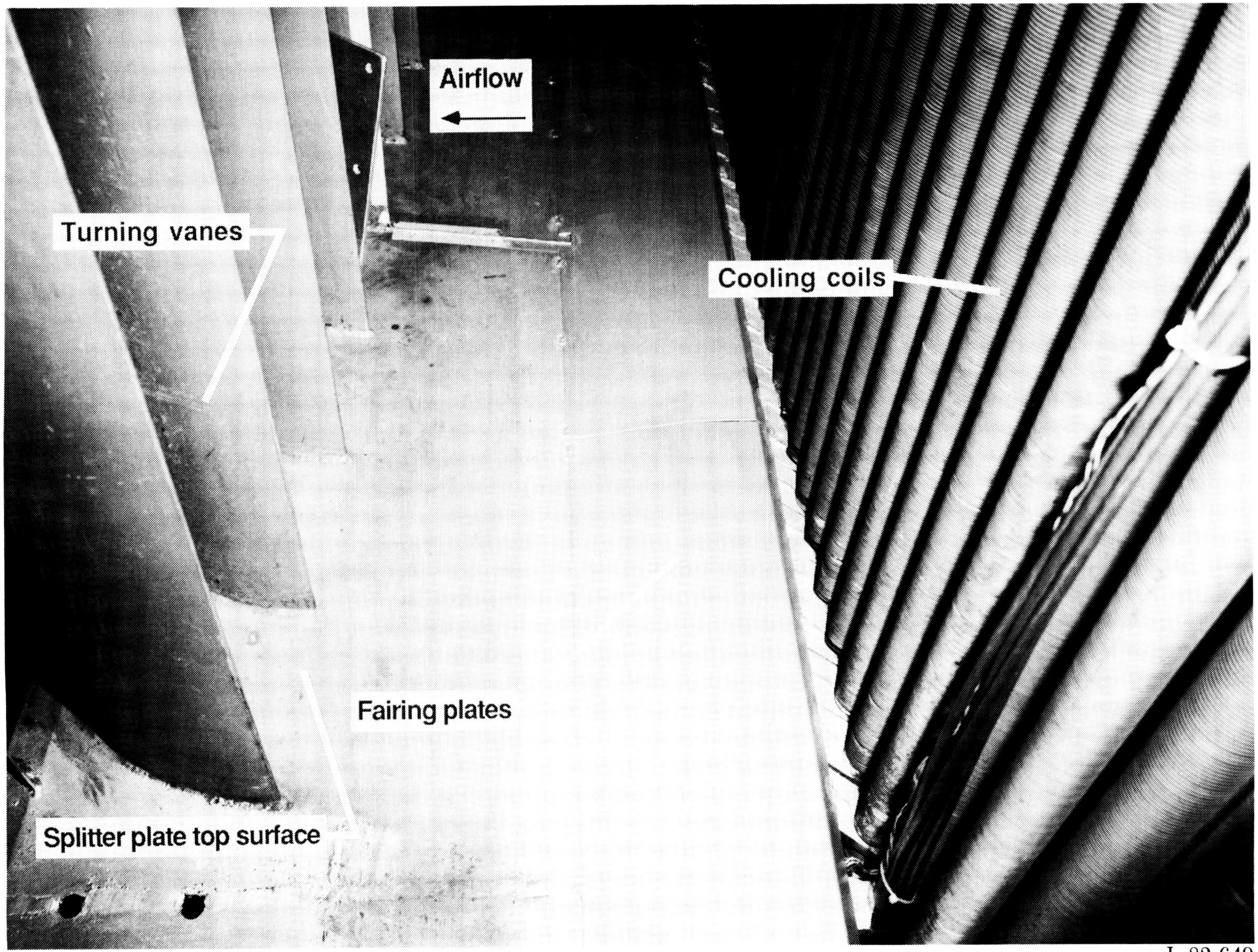
(a) Turning vanes as viewed upstream from test section.

Figure 4. Photographs of turning vanes immediately downstream of cooling coils.



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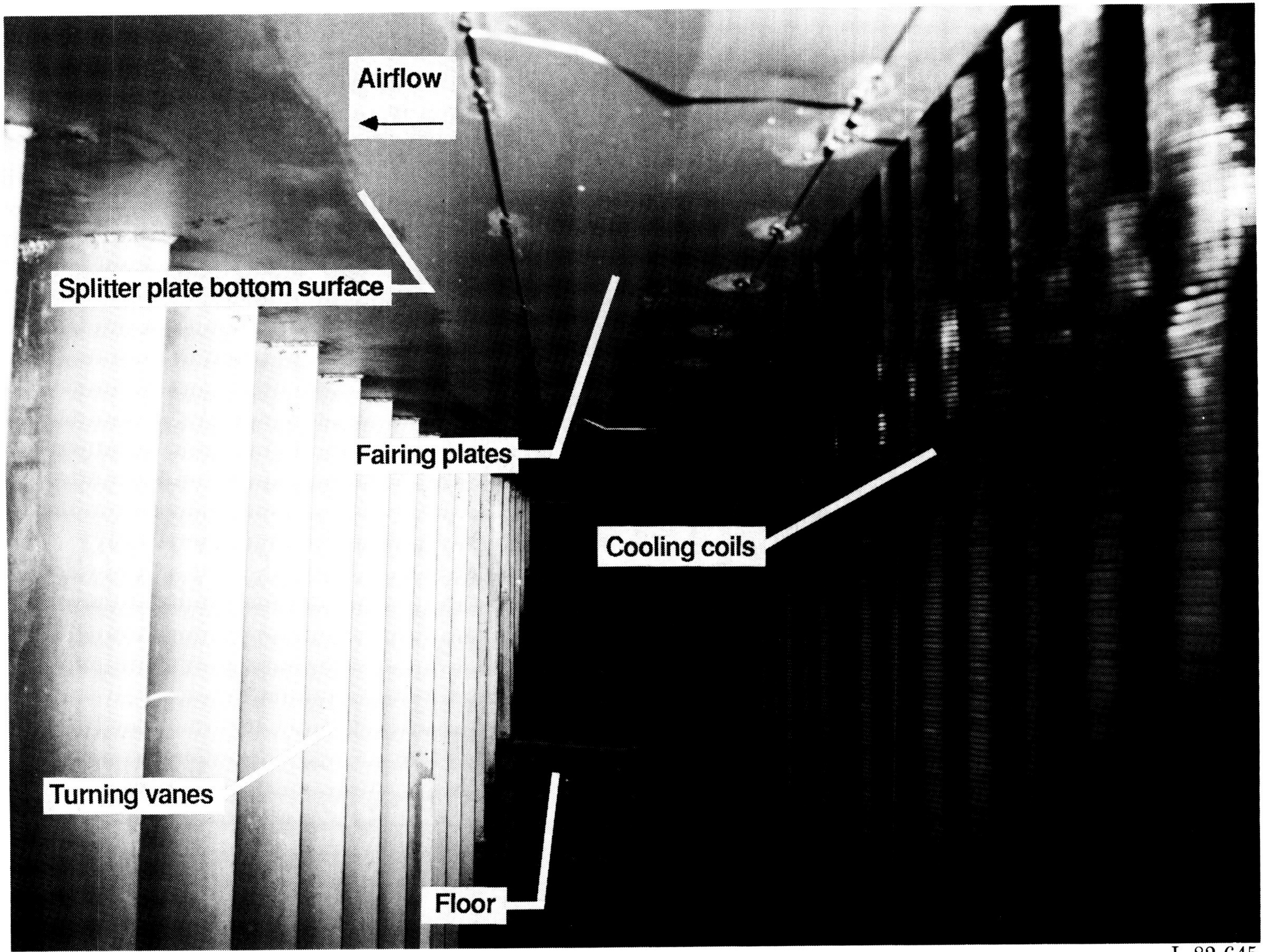
(b) Fairing plates on upper surface of splitter plate.

Figure 4. Continued.



L-82-645

(c) Fairing plates on under surface of splitter plate.

Figure 4. Concluded.

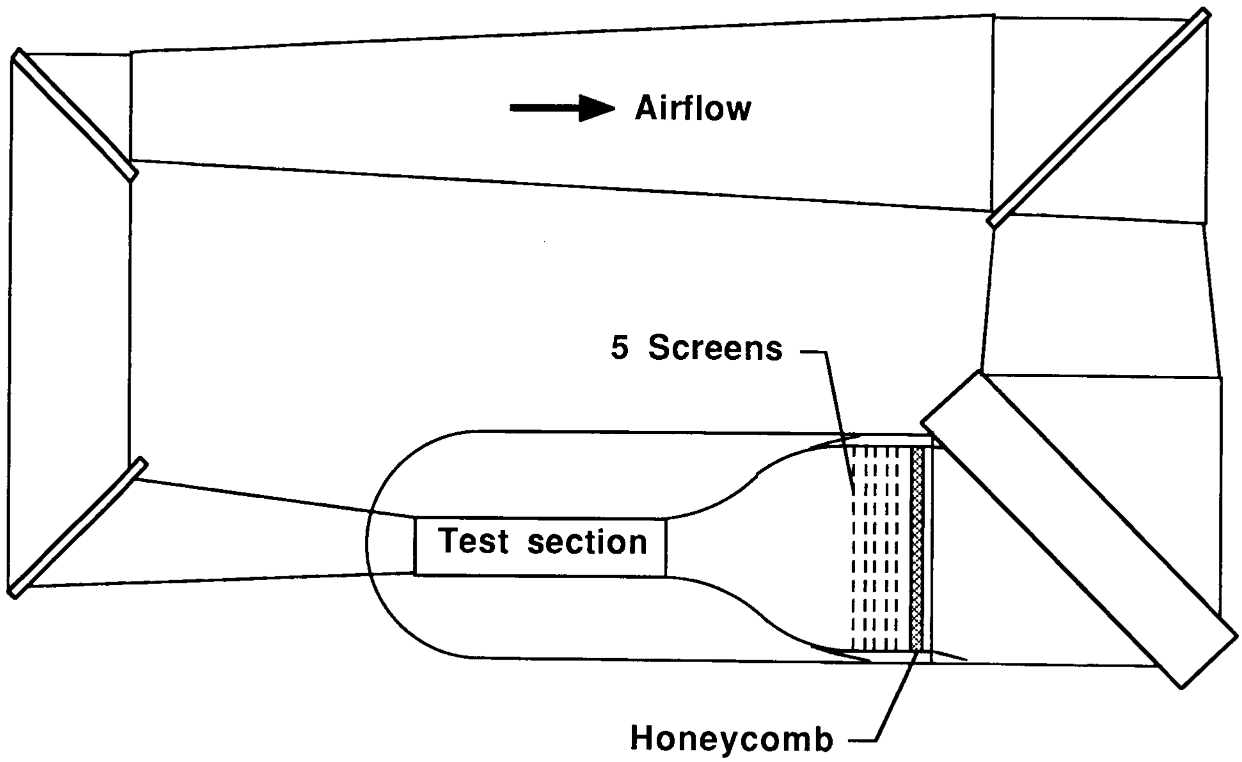


Figure 5. Sketch showing location of honeycomb and screens relative to overall tunnel circuit.

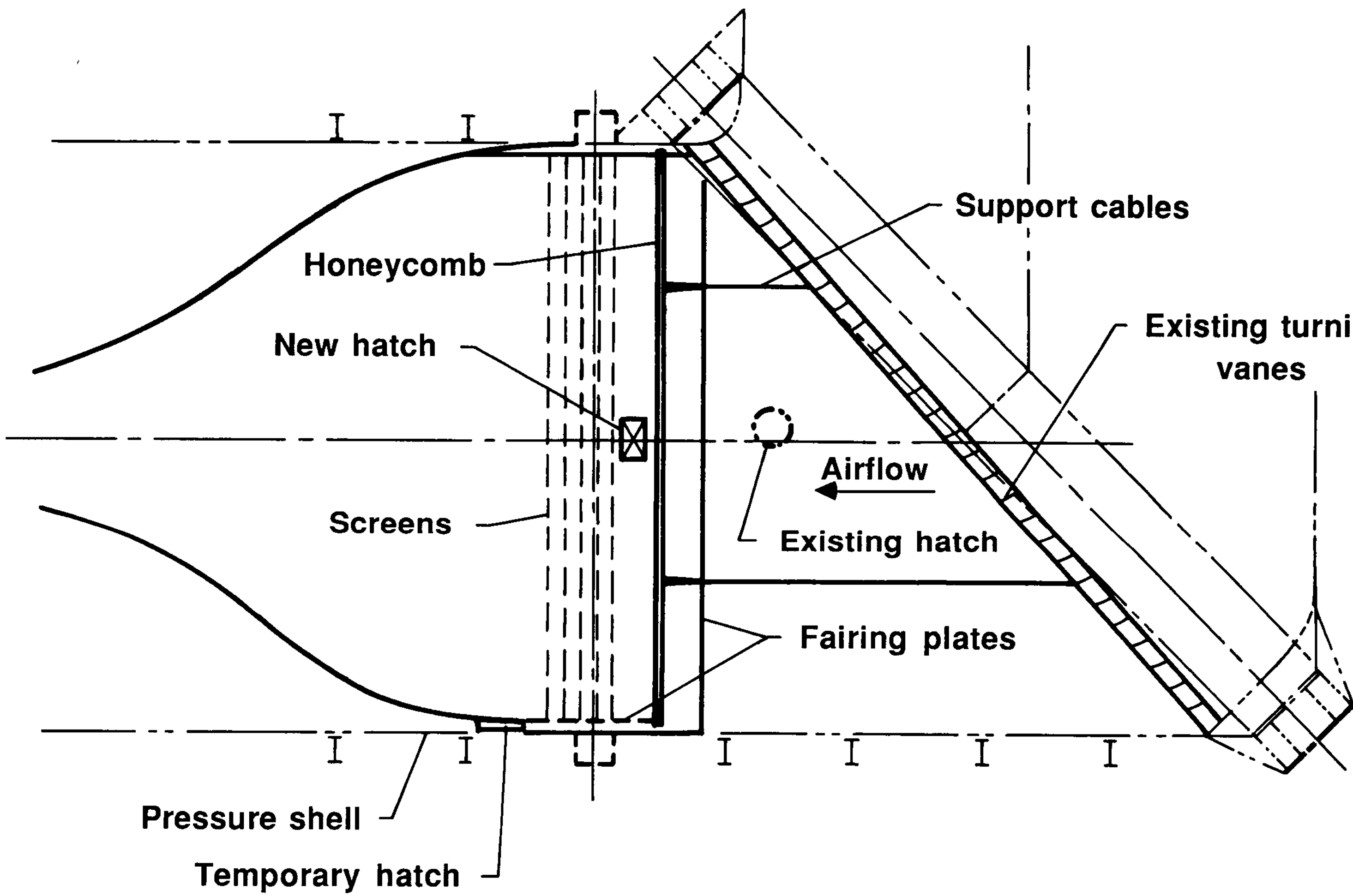


Figure 6. Sketch of general installation of honeycomb and screens.

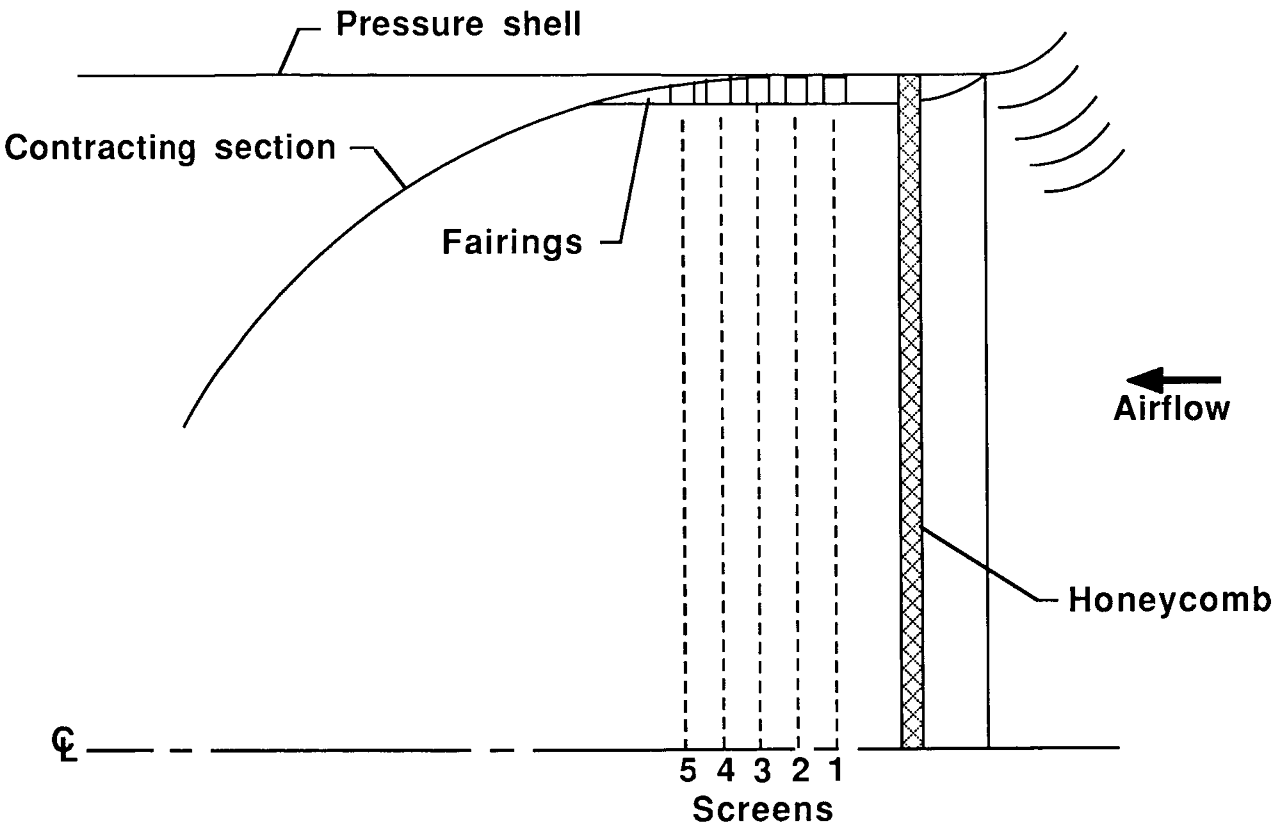
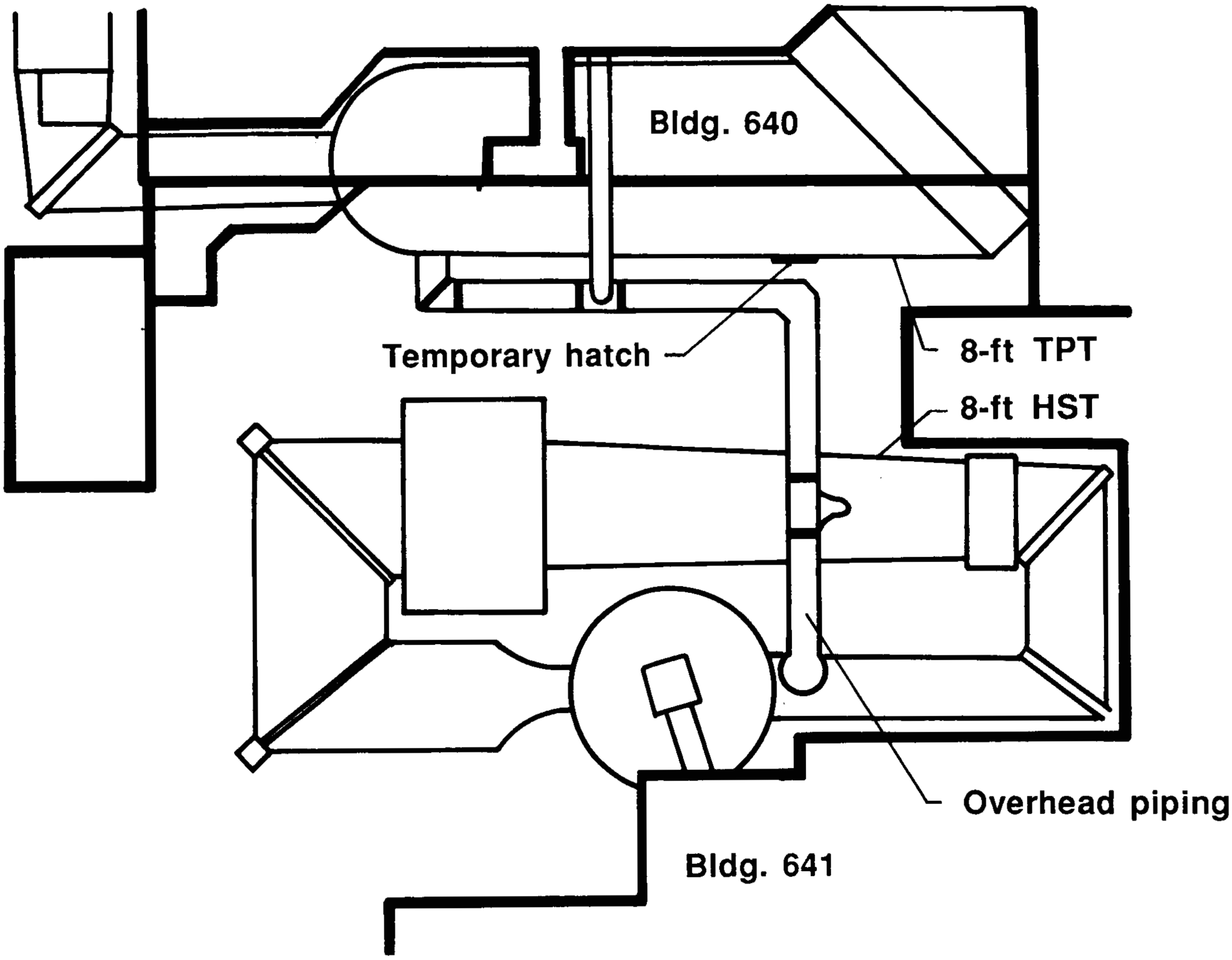
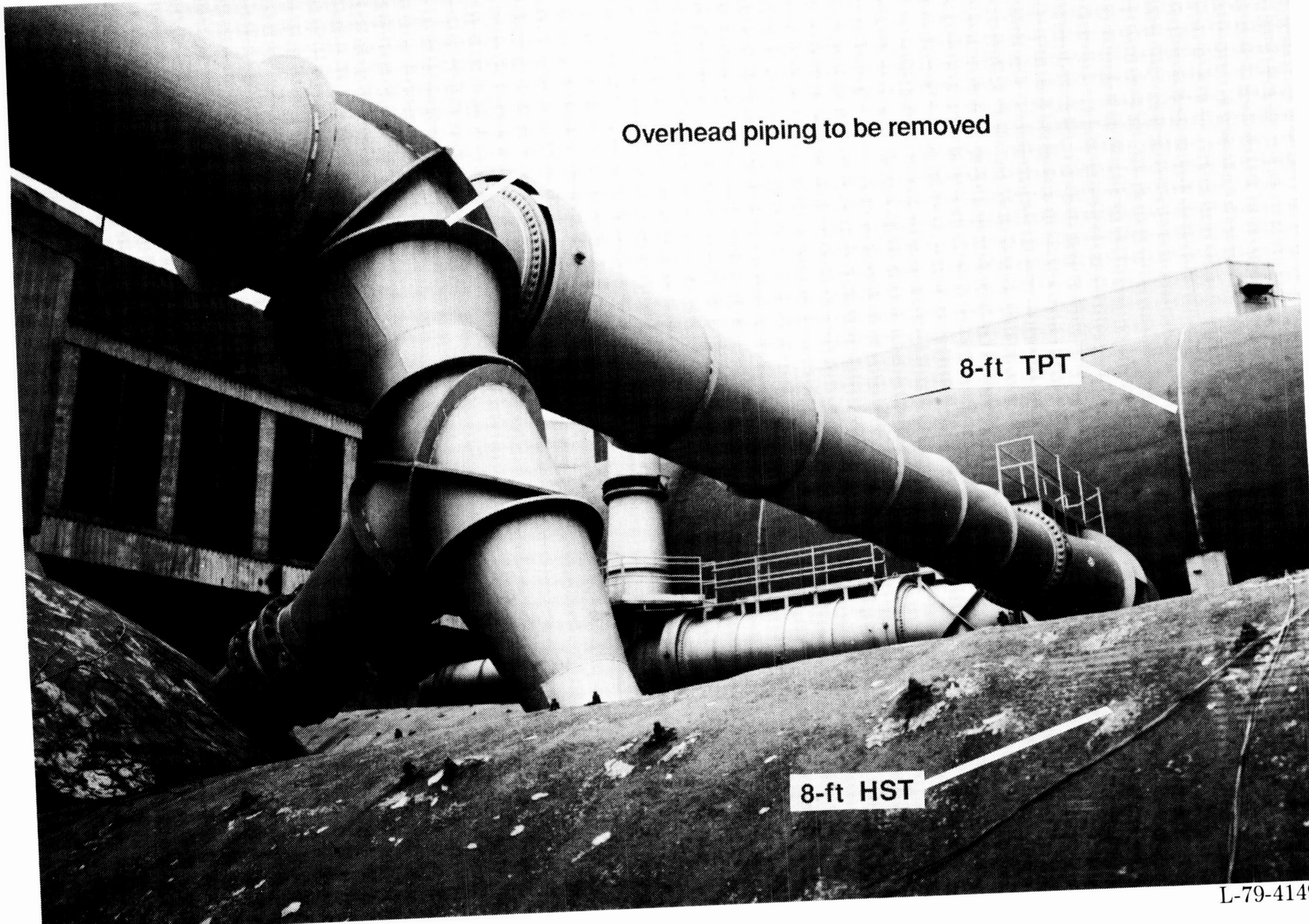


Figure 7. Sketch of fairings around perimeter of honeycomb and screens.



(a) Sketch.

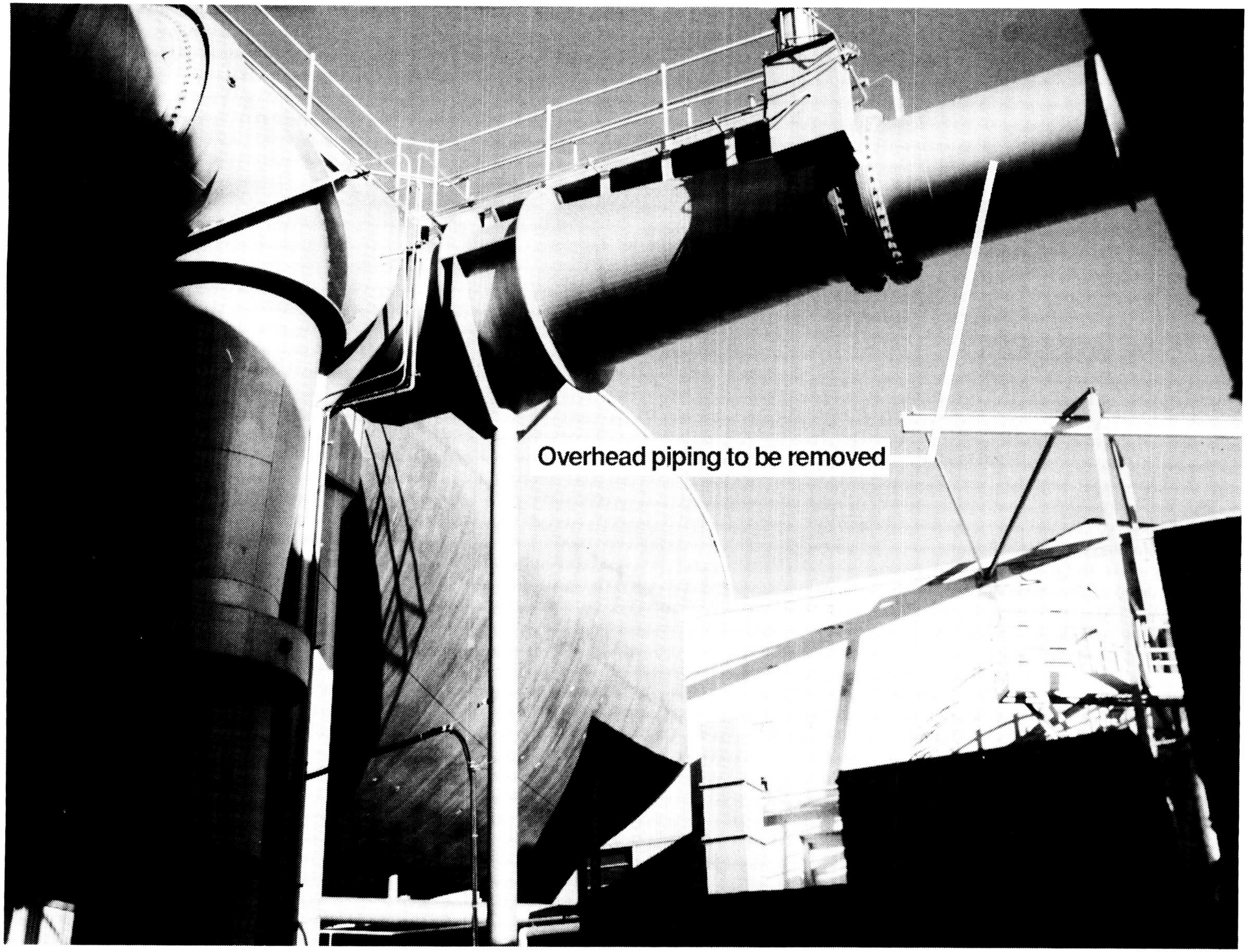
Figure 8. Sketch and photographs of existing external overhead piping between 8-ft TPT and 8-ft HST.



L-79-4149

(b) Photographs.

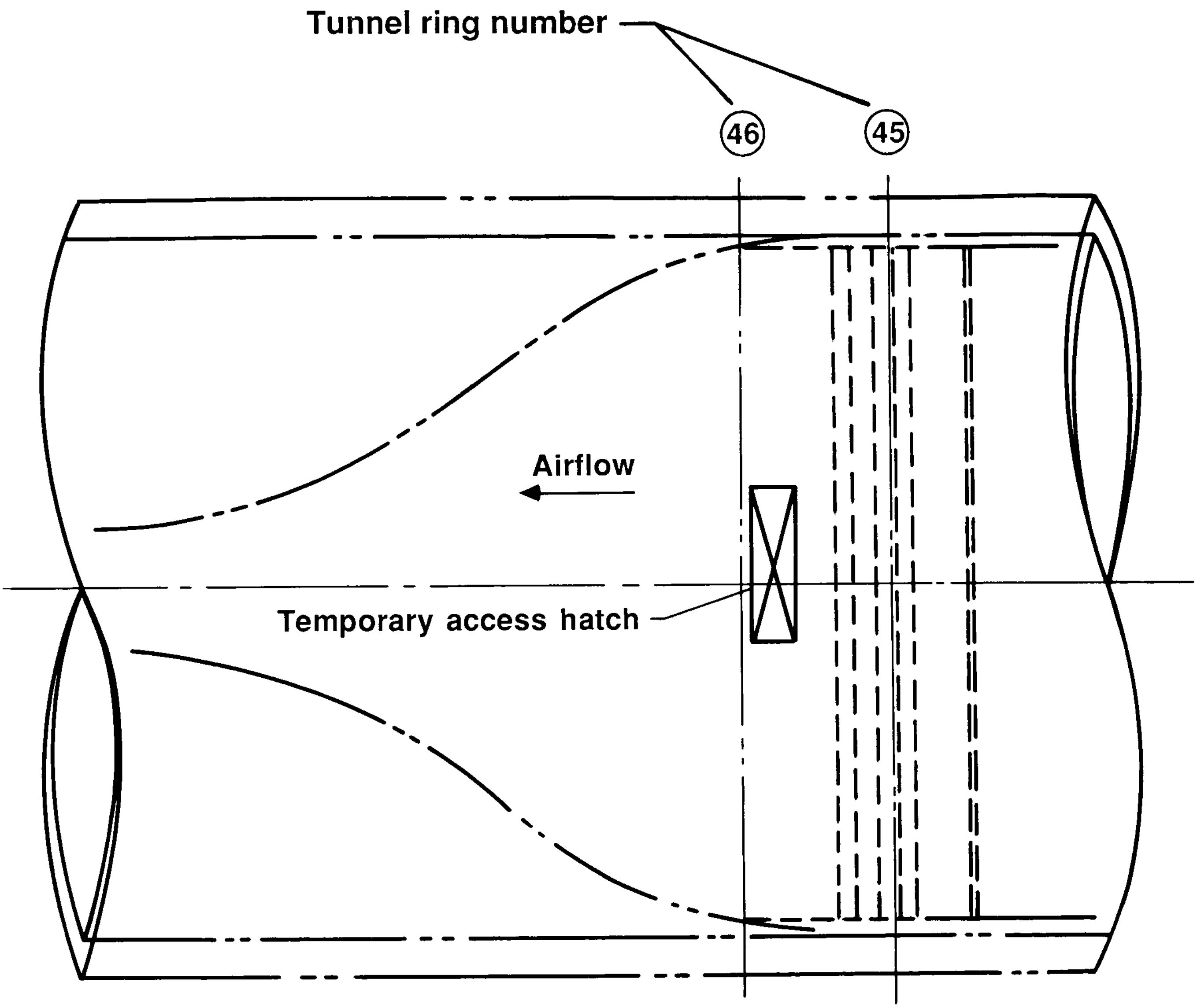
Figure 8. Continued.



L-78-8582

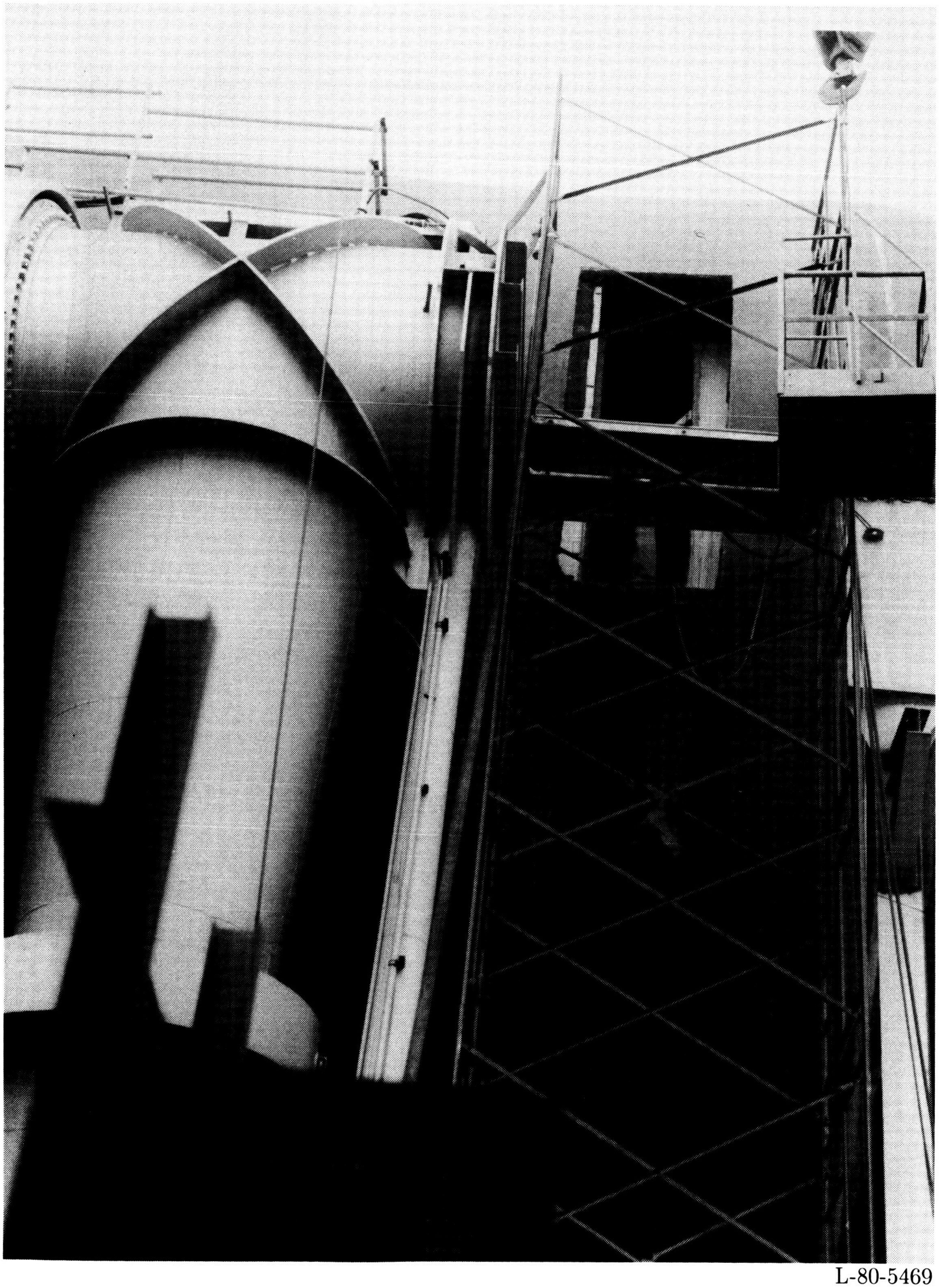
(b) Concluded.

Figure 8. Concluded.



(a) Sketch.

Figure 9. Sketch showing location of temporary hatch (side view) and photographs during installation.



L-80-5469

(c) External view of temporary access hatch.

Figure 9. Continued.

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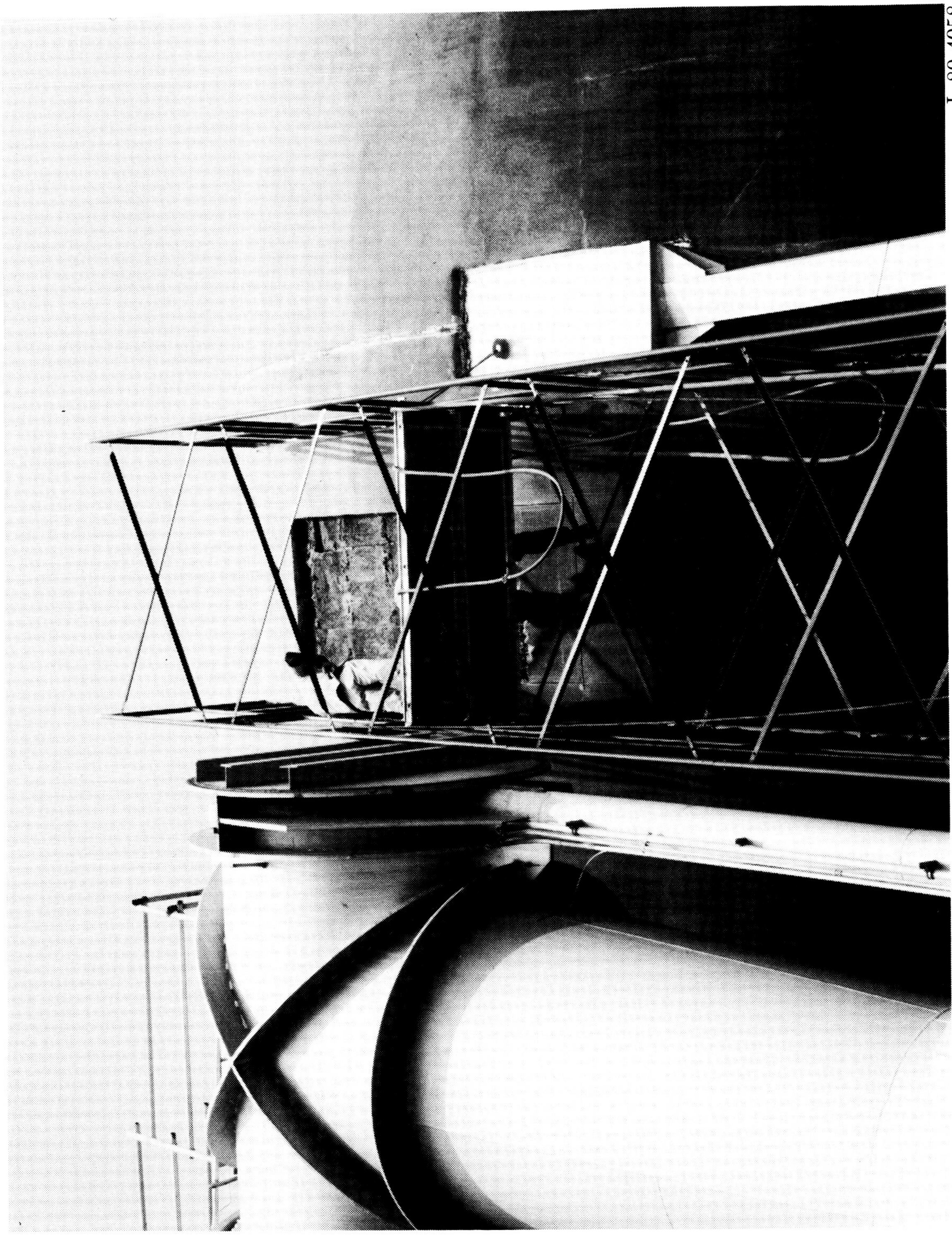

L-80-4958

(b) Cutting away of shotcrete.

Figure 9. Continued.

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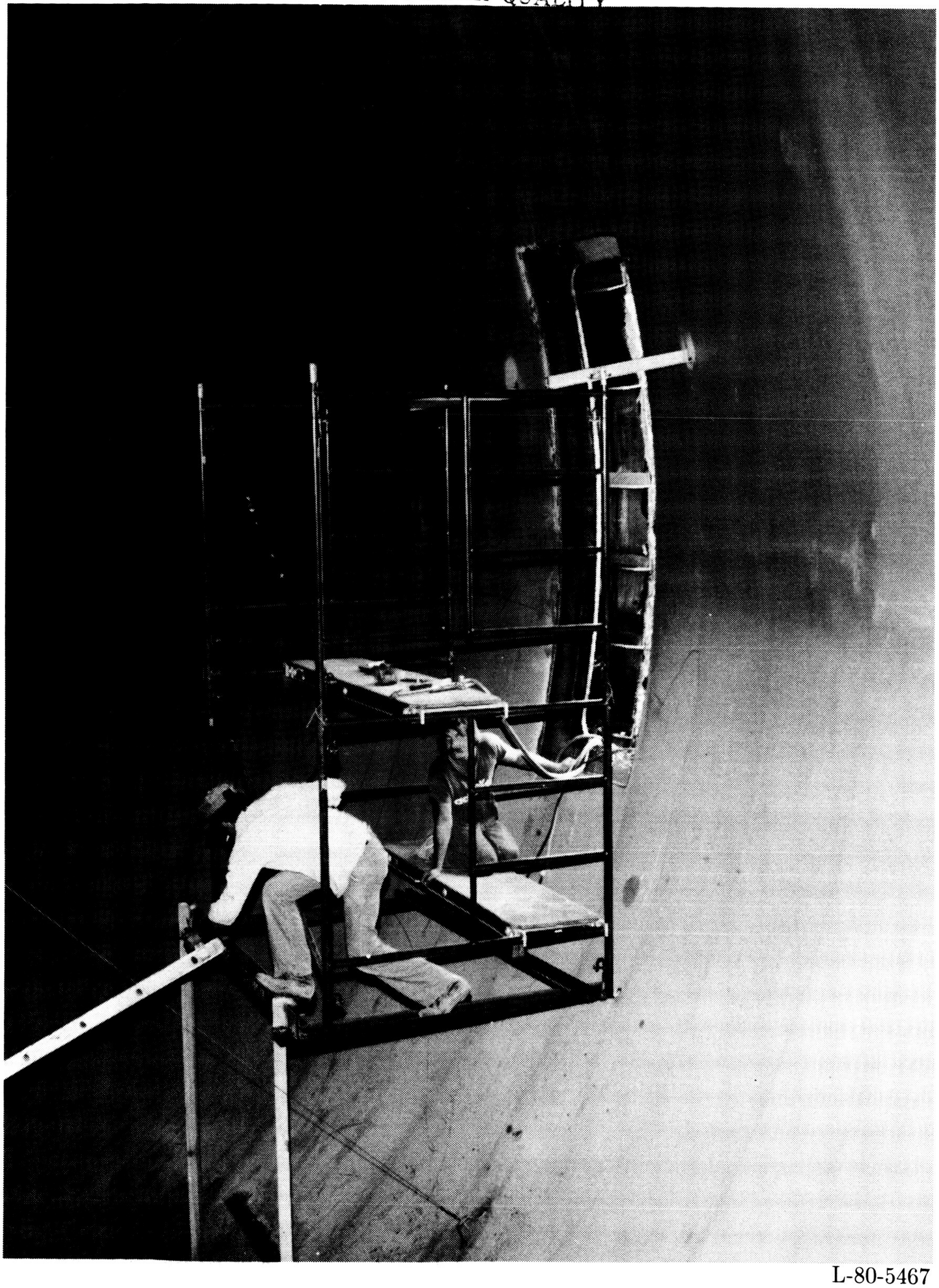
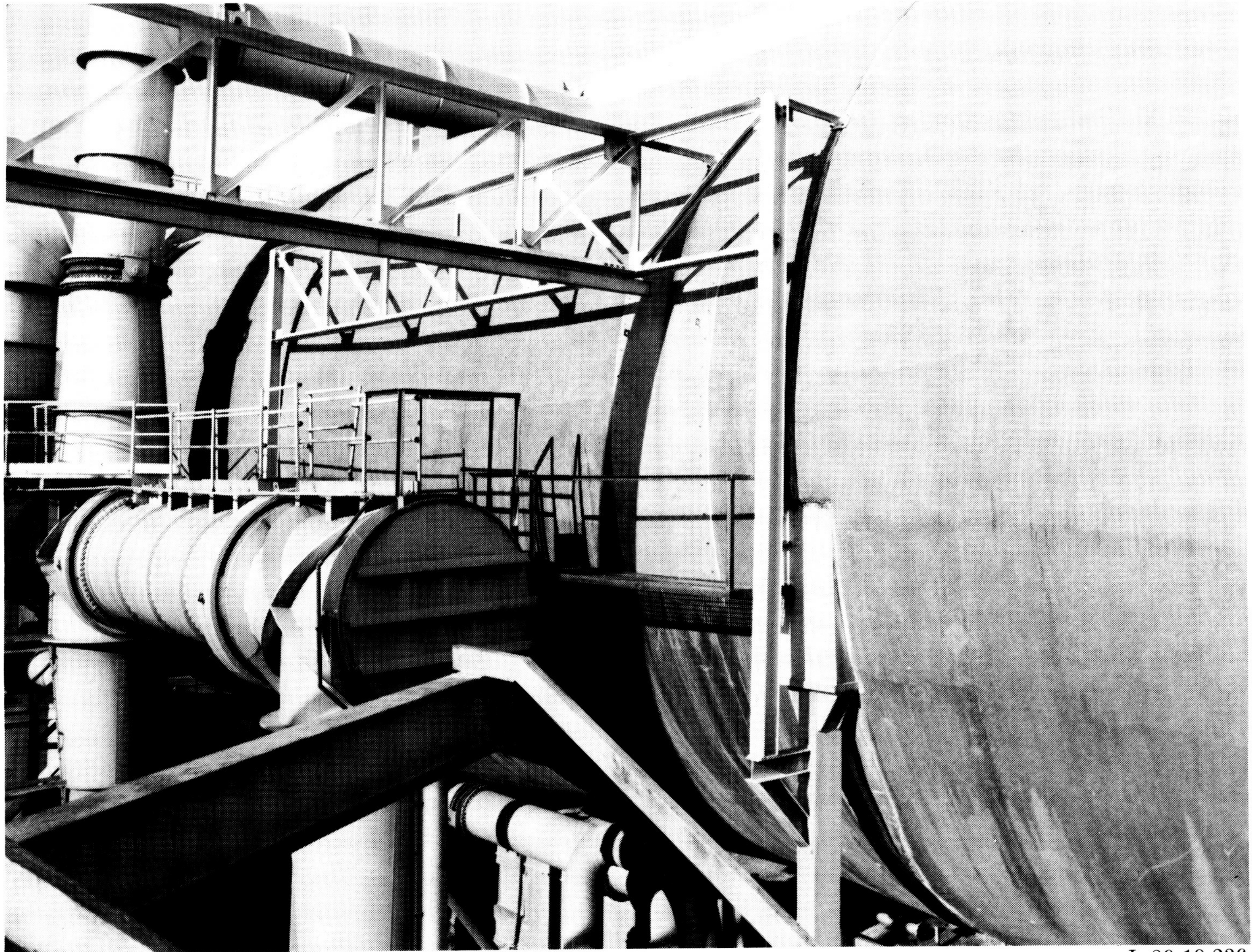


L-80-5467

(d) Interior view of temporary access hatch.

Figure 9. Continued.



L-86-10,236

(e) Exterior view of temporary hatch after sealing.

Figure 9. Concluded.

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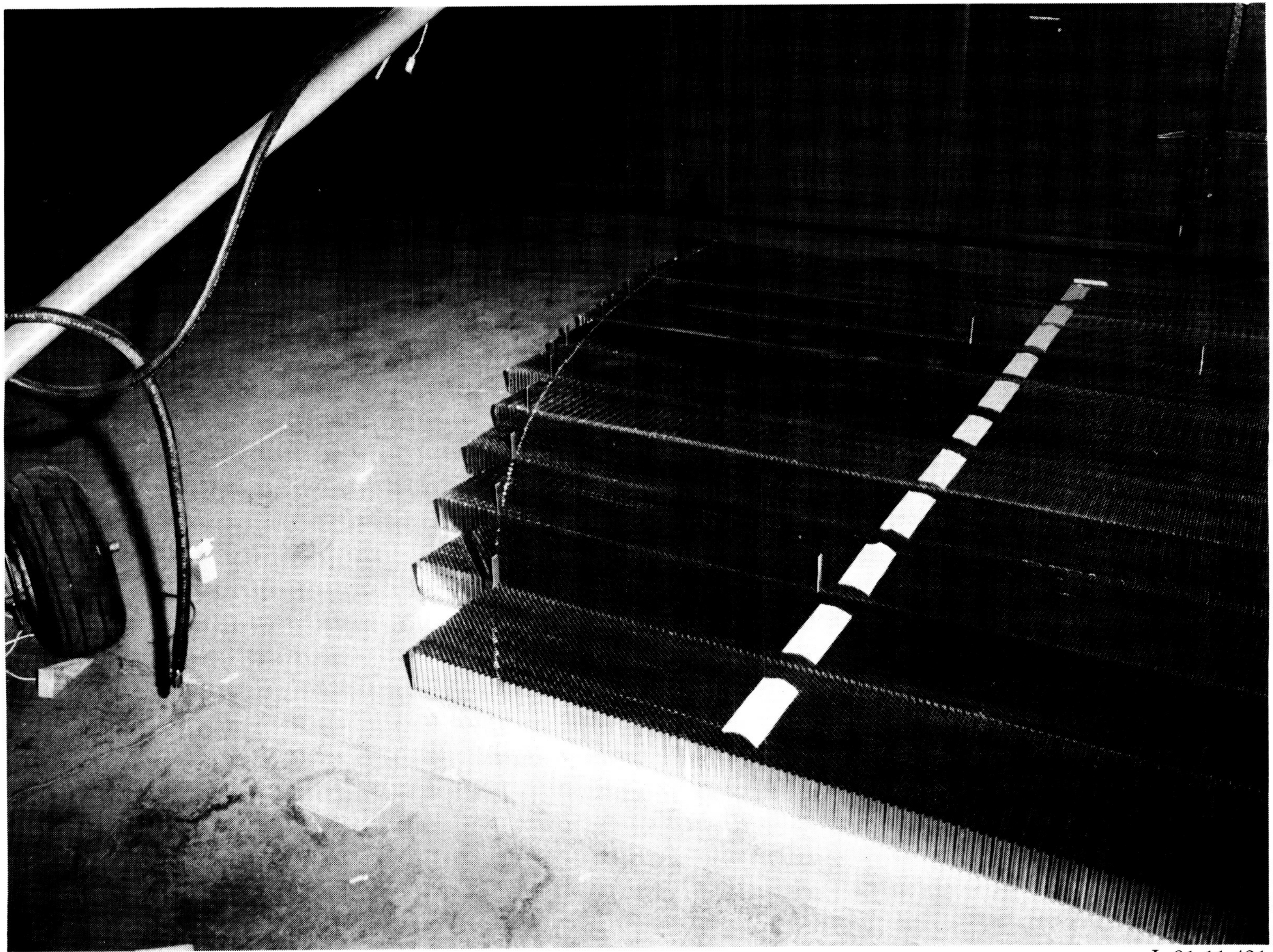
L-81-6951

Figure 10. Remote assembly of honeycomb panels.



L-81-11,421

Figure 10. Concluded.

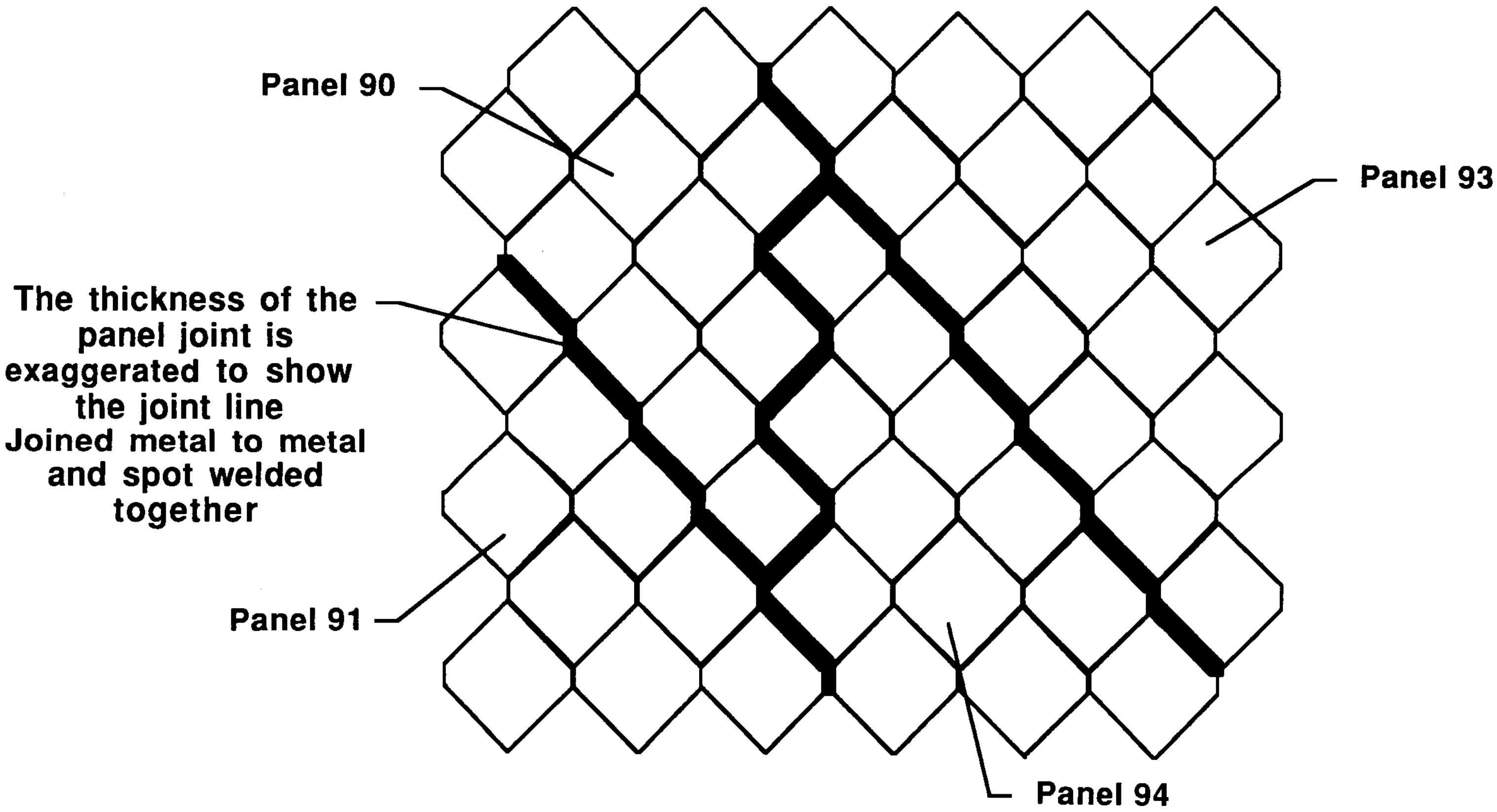
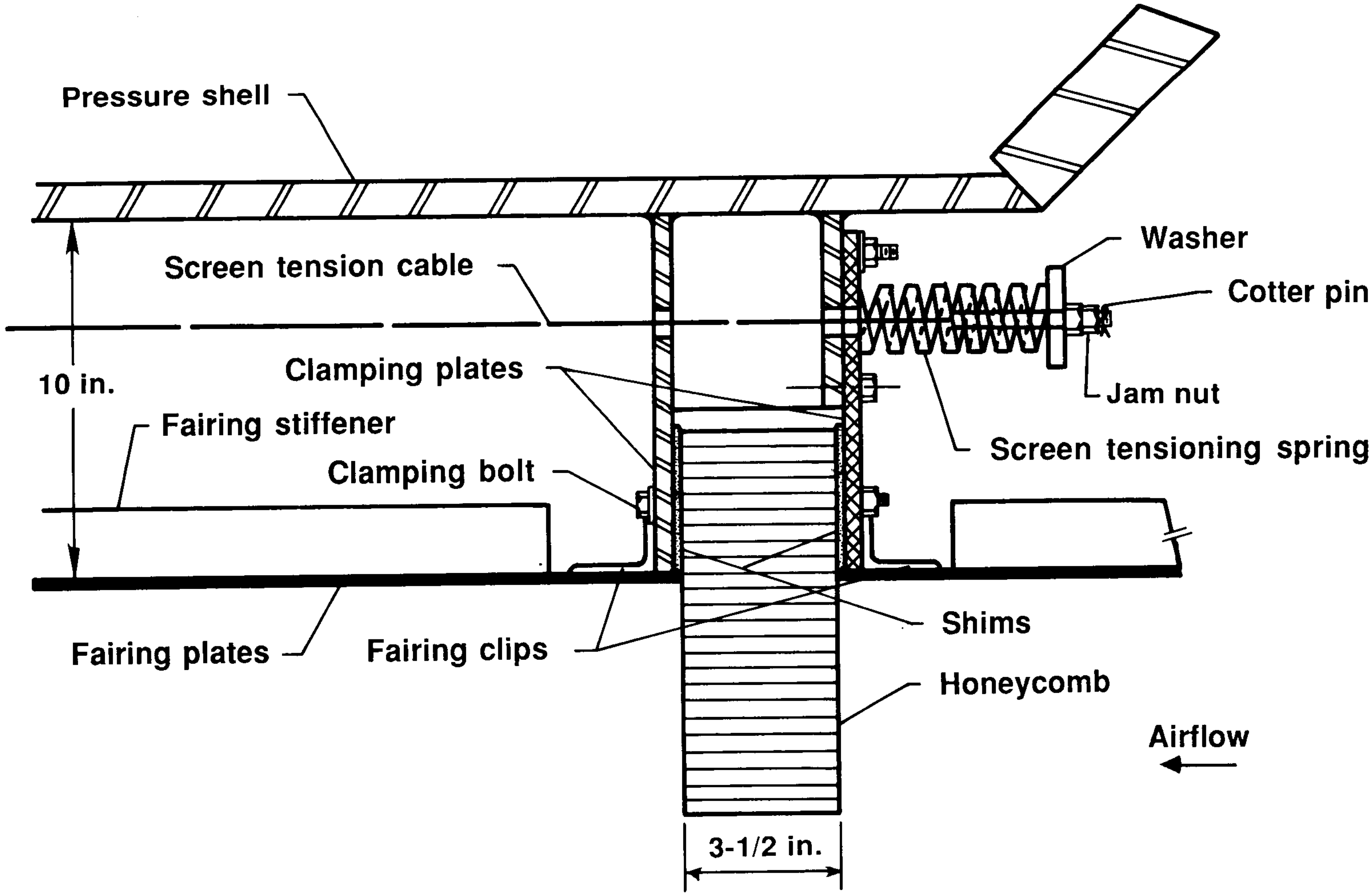
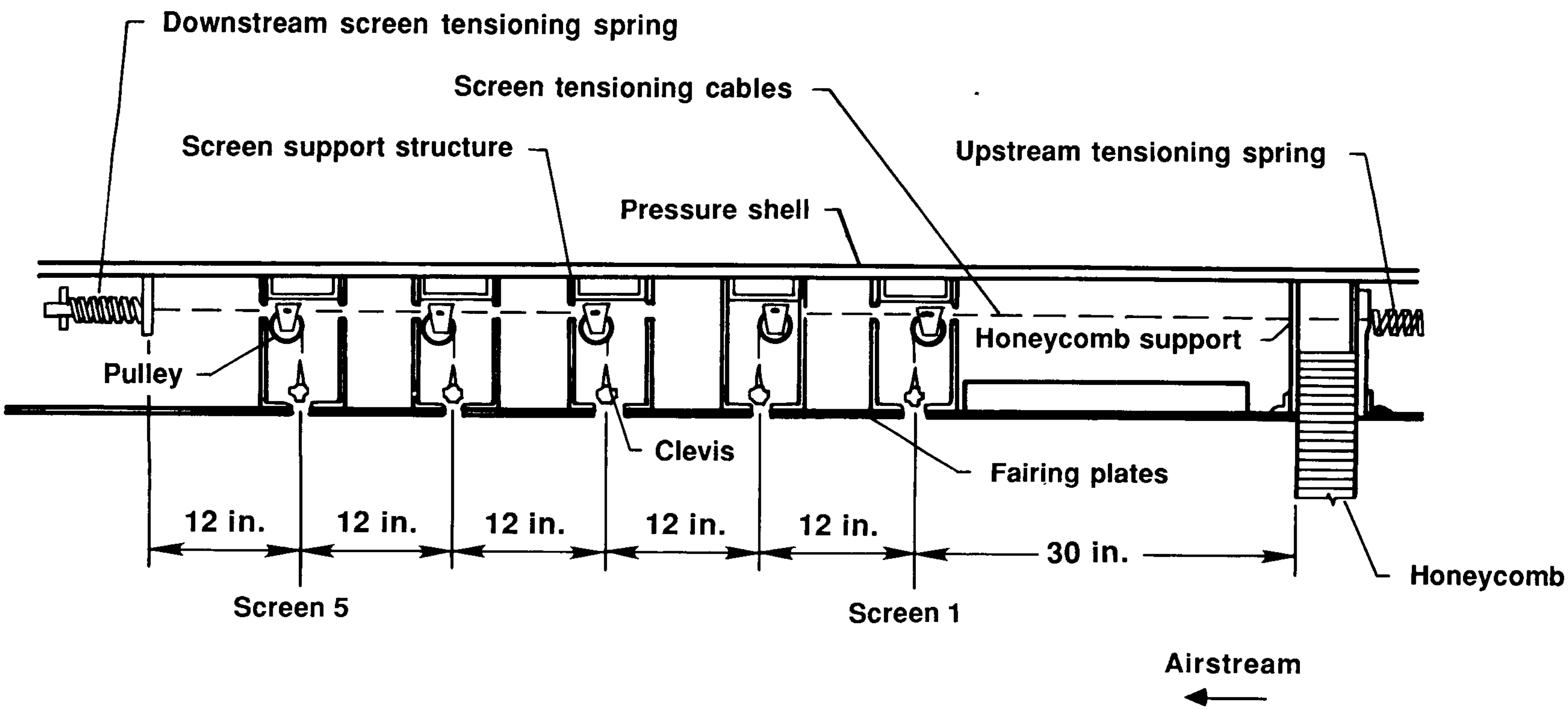


Figure 11. Sketch showing corners of honeycomb panels joined together.



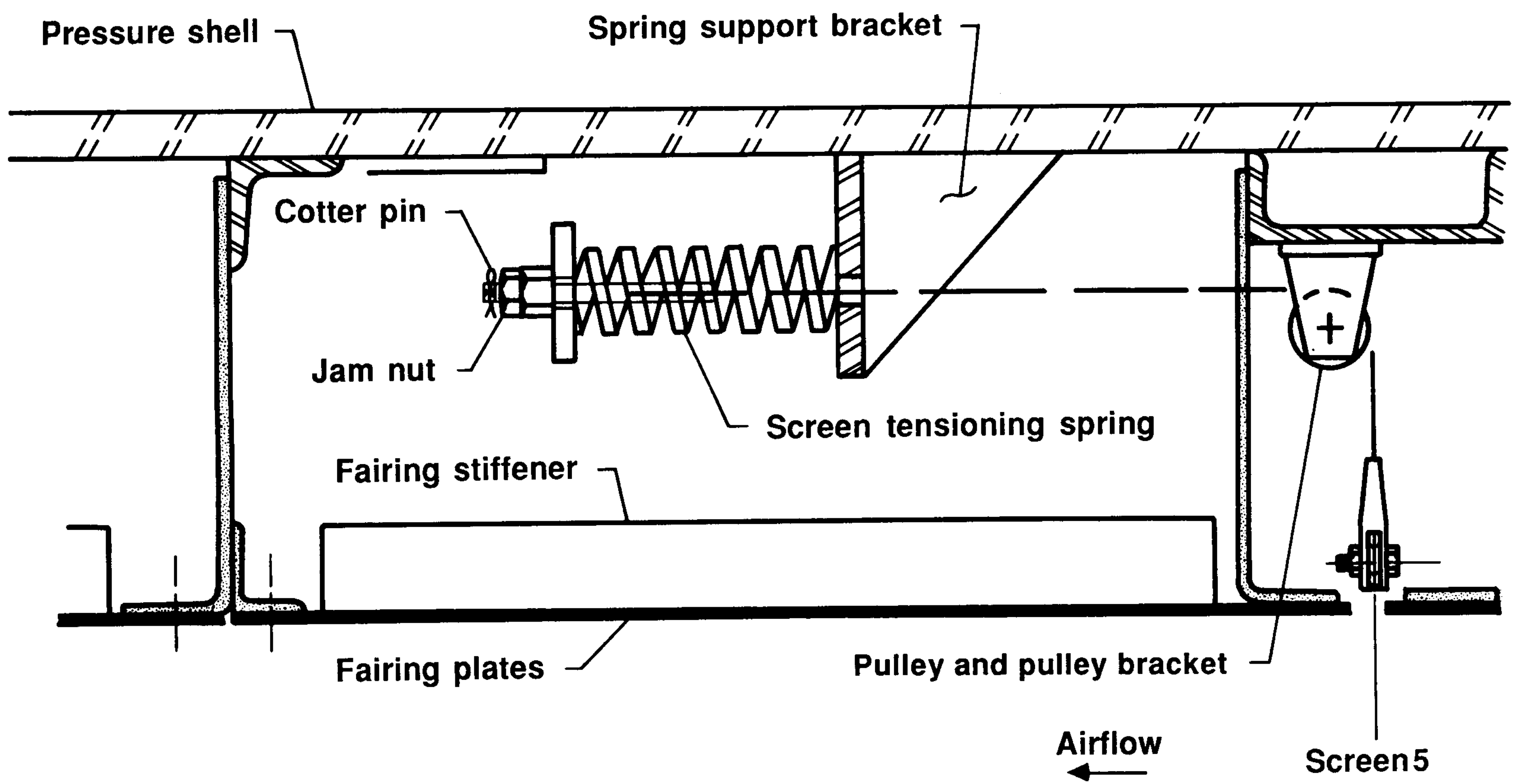
(a) Honeycomb support structure and upstream screen tensioning spring support.

Figure 12. Sketches of honeycomb and screen support structure.



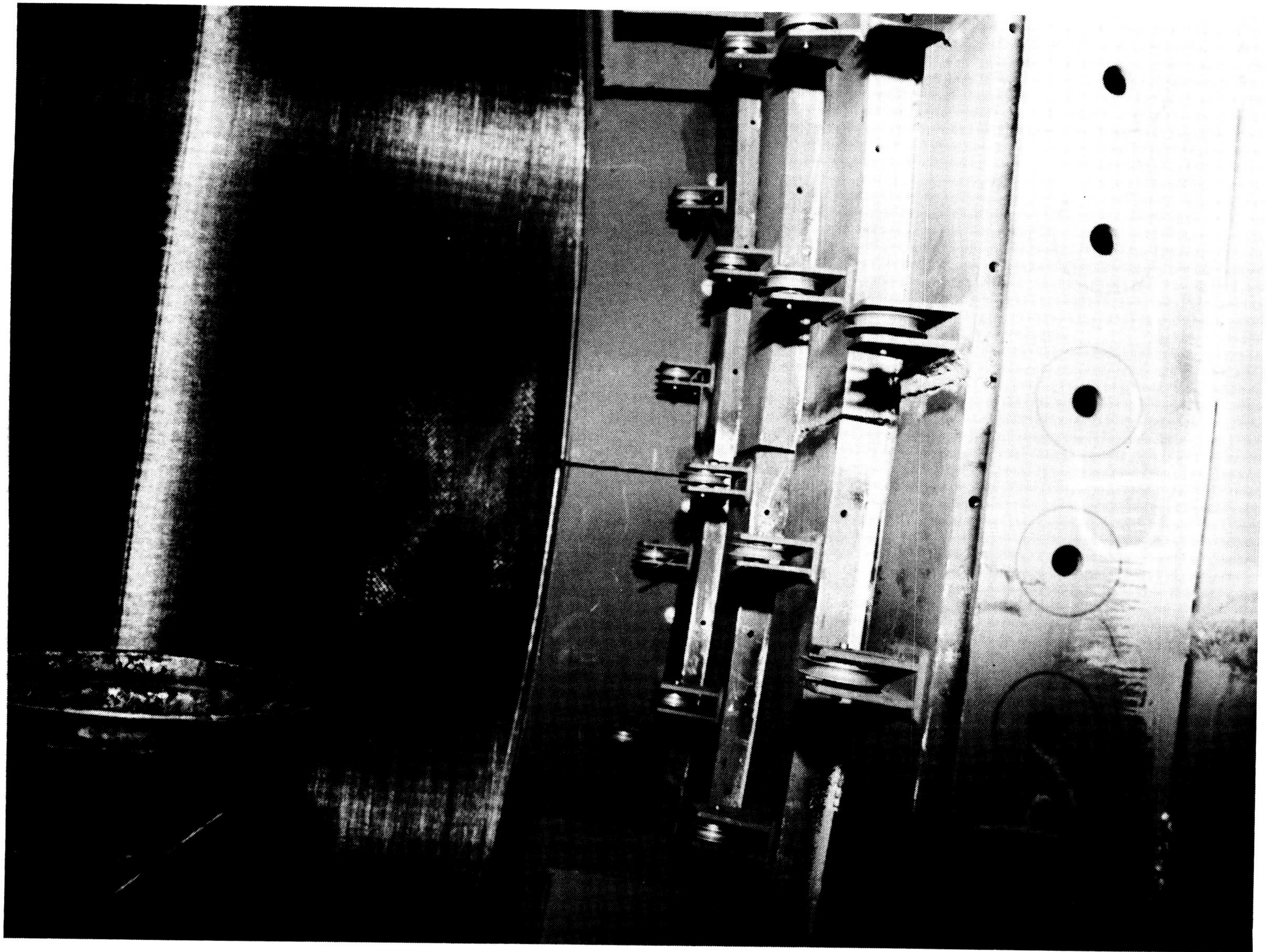
(b) General layout of honeycomb and screen support structure.

Figure 12. Continued.



(c) Downstream screen tensioning spring support.

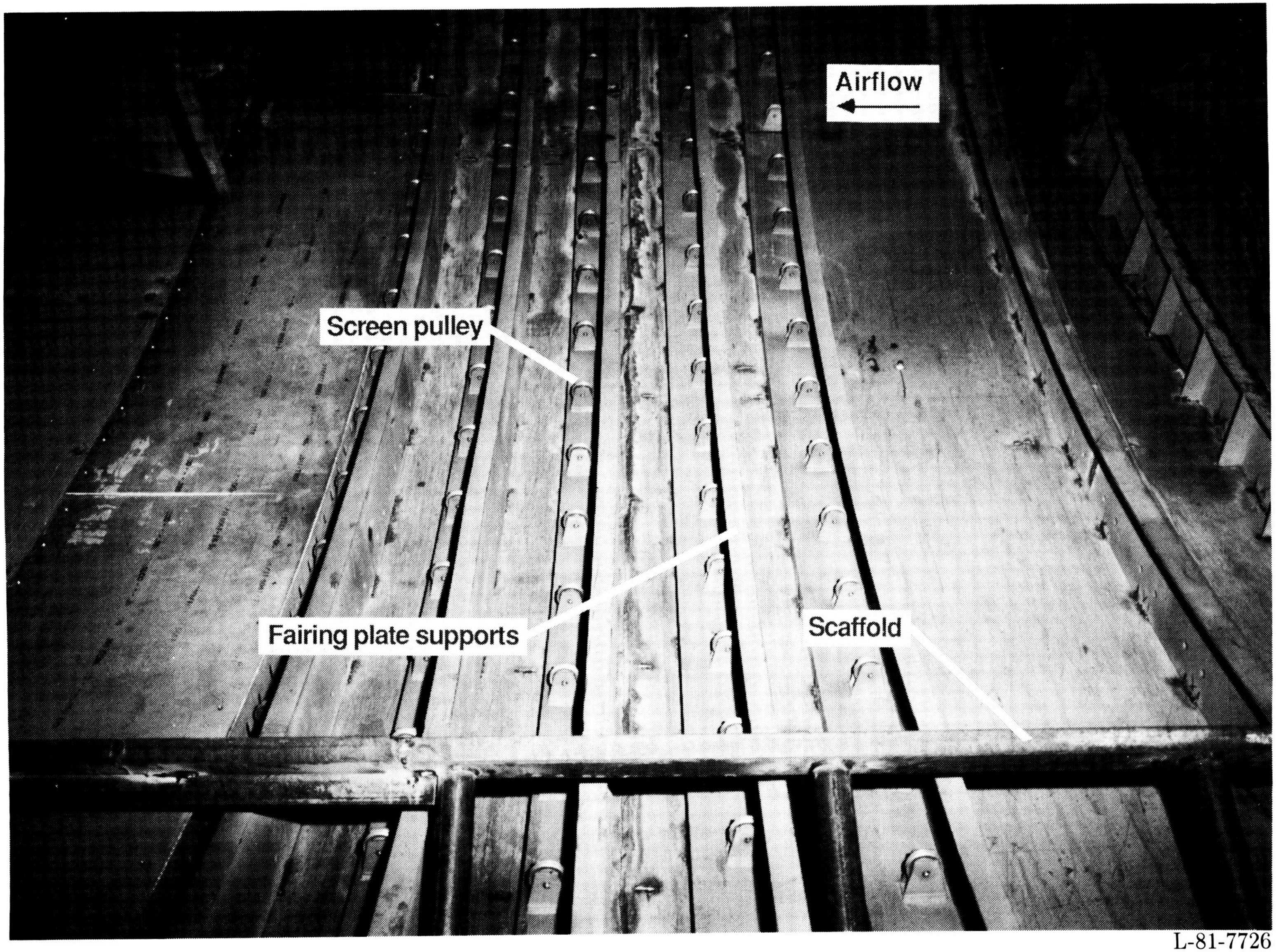
Figure 12. Concluded.



L-81-11,048

(a) Pulleys and pulley supports.

Figure 13. Photographs during various stages of installation of honeycomb and screen mounting hardware.



L-81-7726

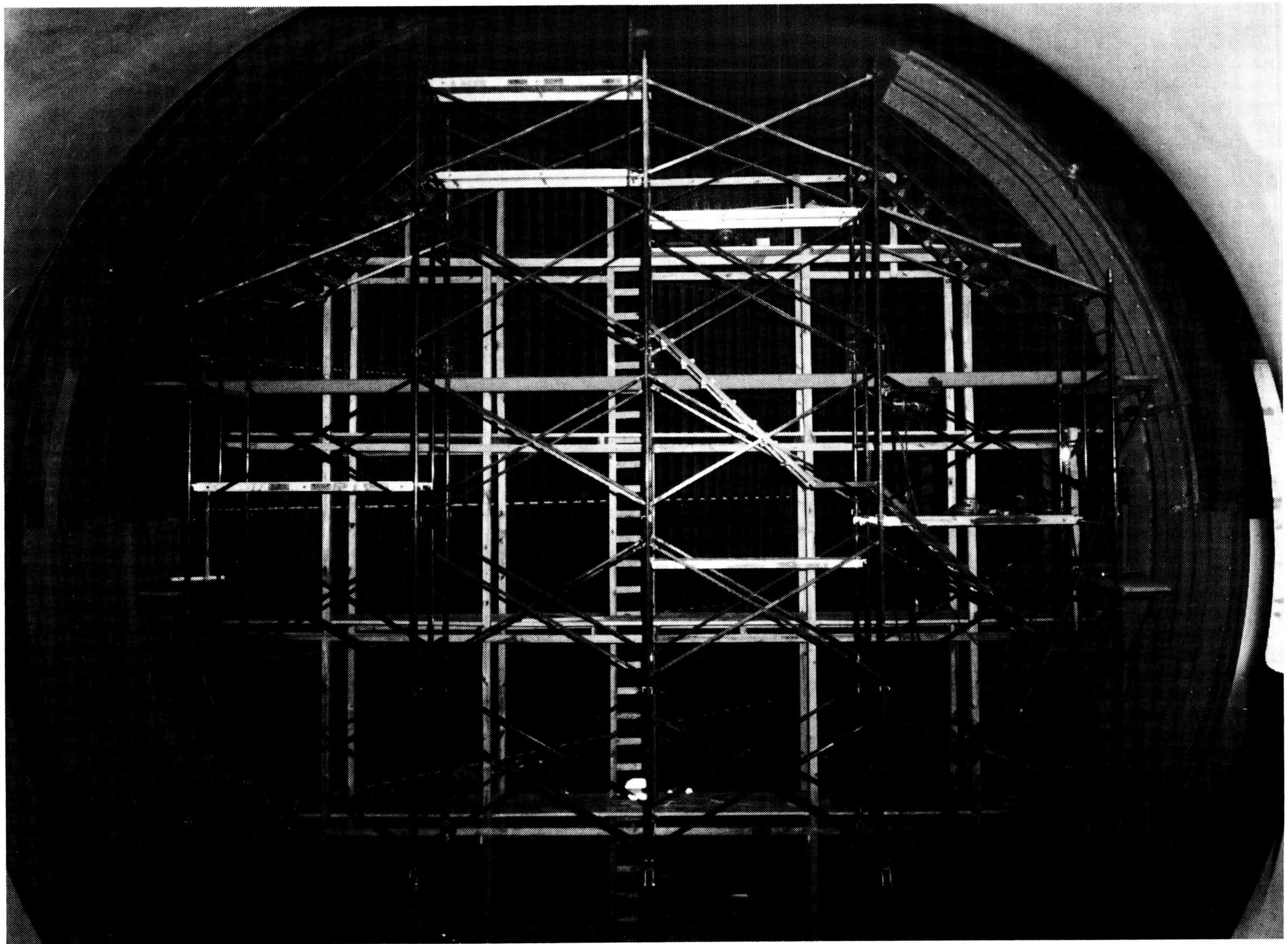
(b) Screen fairing plate supports.

Figure 13. Continued.

L-81-5489

(c) Progression of installation around perimeter of settling chamber.

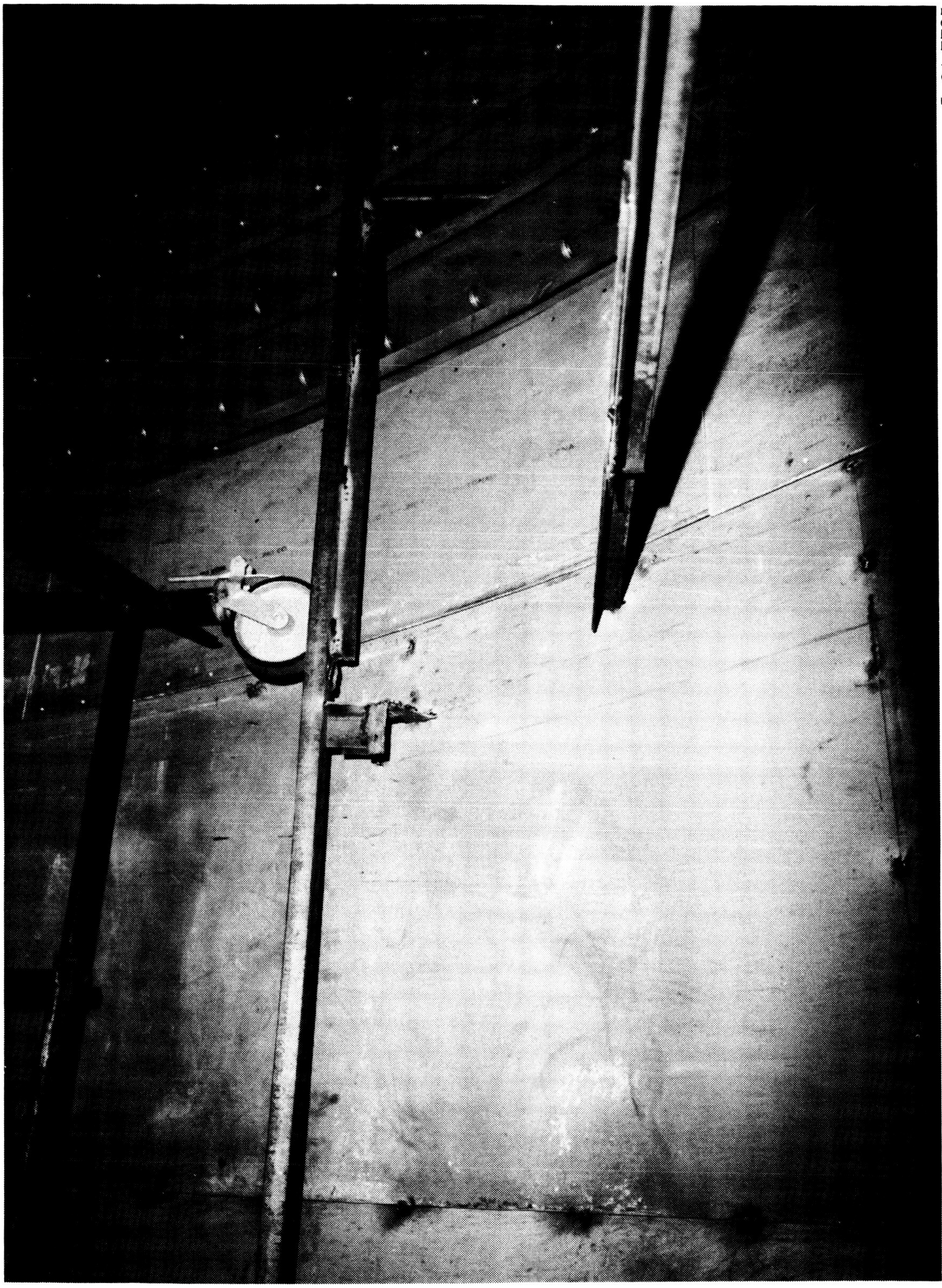
Figure 13. Continued.



L-81-6186

(c) Concluded.

Figure 13. Concluded.



L-81-7725

Figure 14. Rolling scaffolding.

L-81-7723

Figure 15. Wooden scaffolding upstream of honeycomb.

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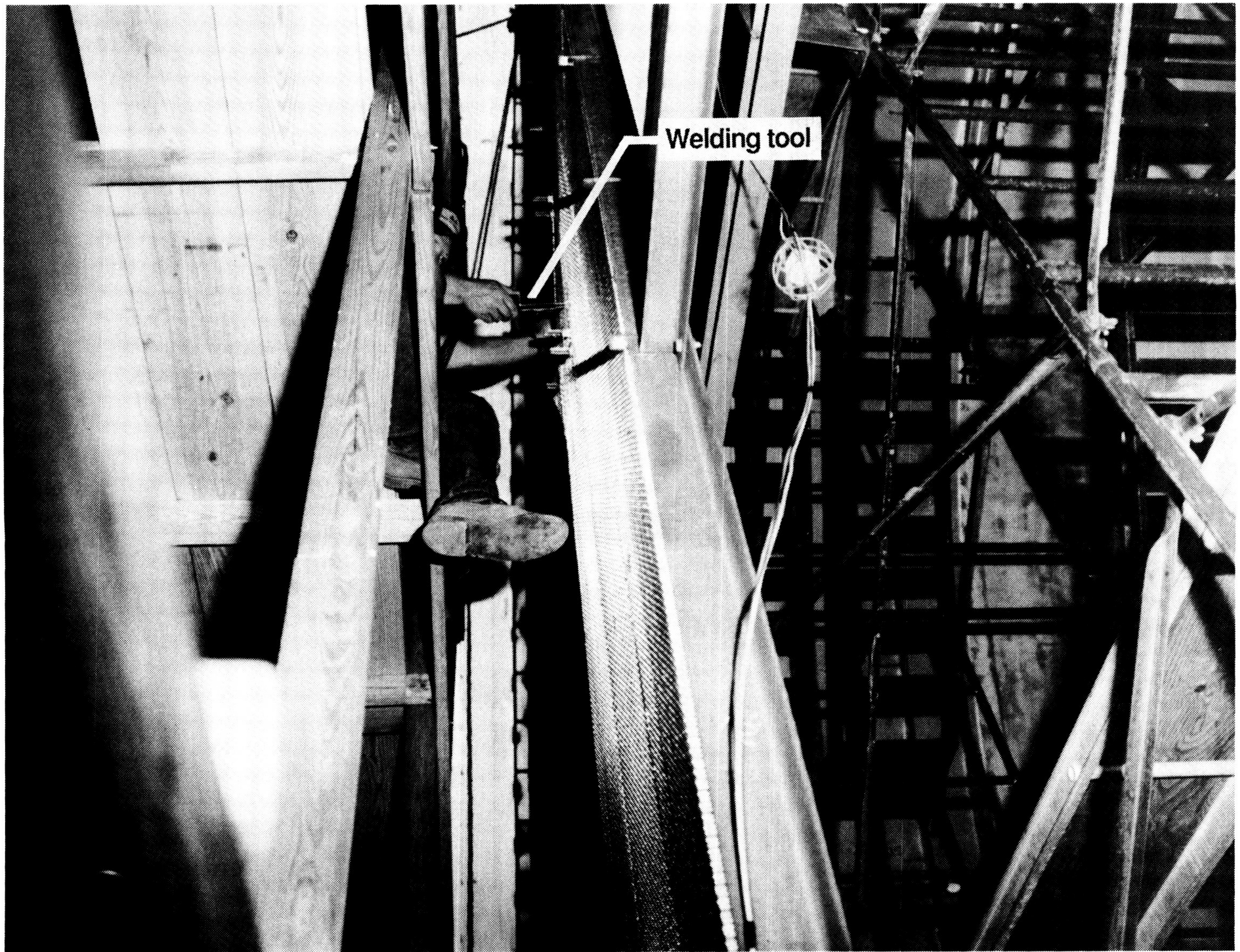
L-81-7728

Figure 15. Continued.

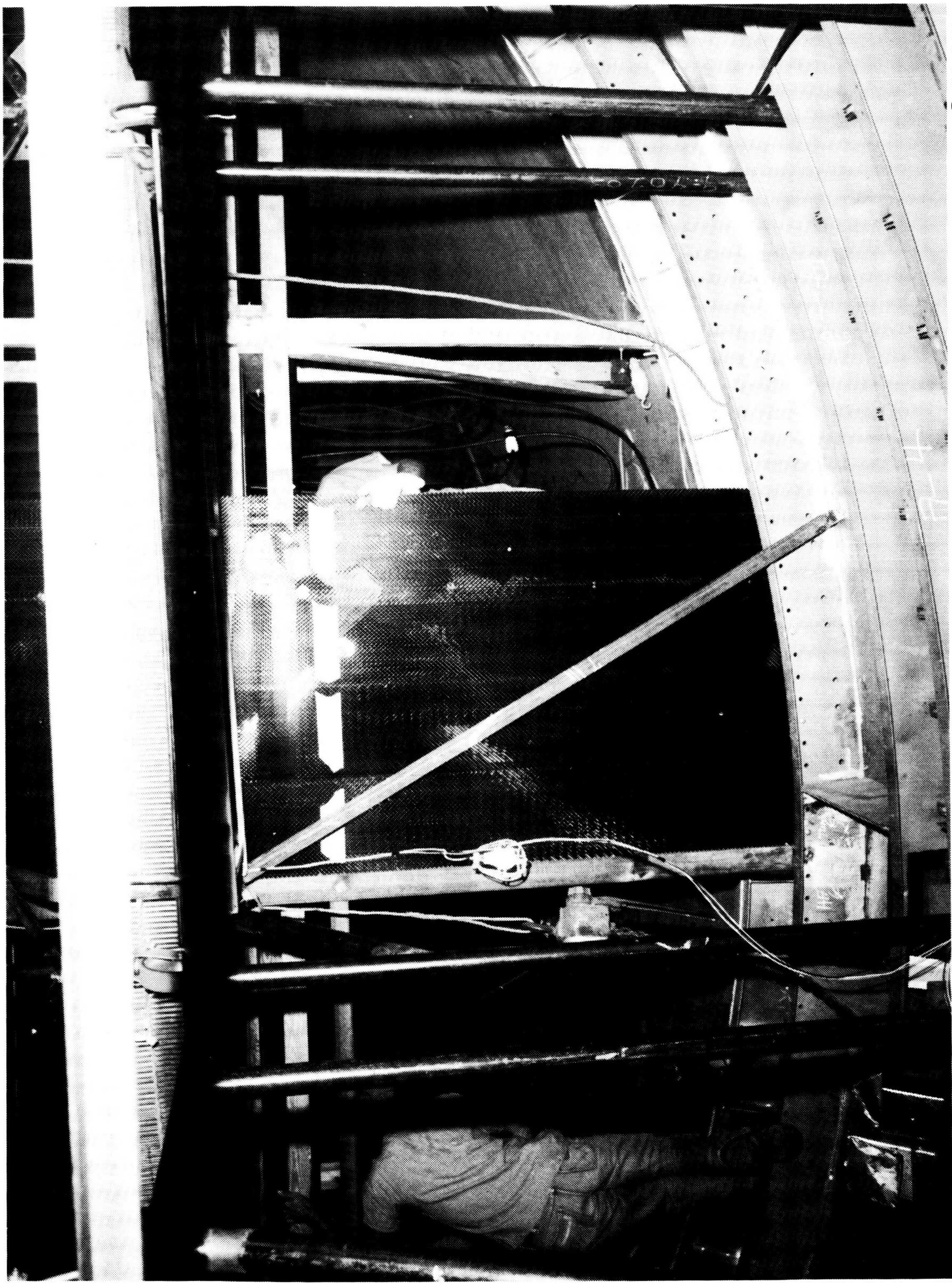
Figure 15. Concluded.



L-81-8491

(a) Installation of first panels.

Figure 16. Honeycomb panel installation.



L-81-8497

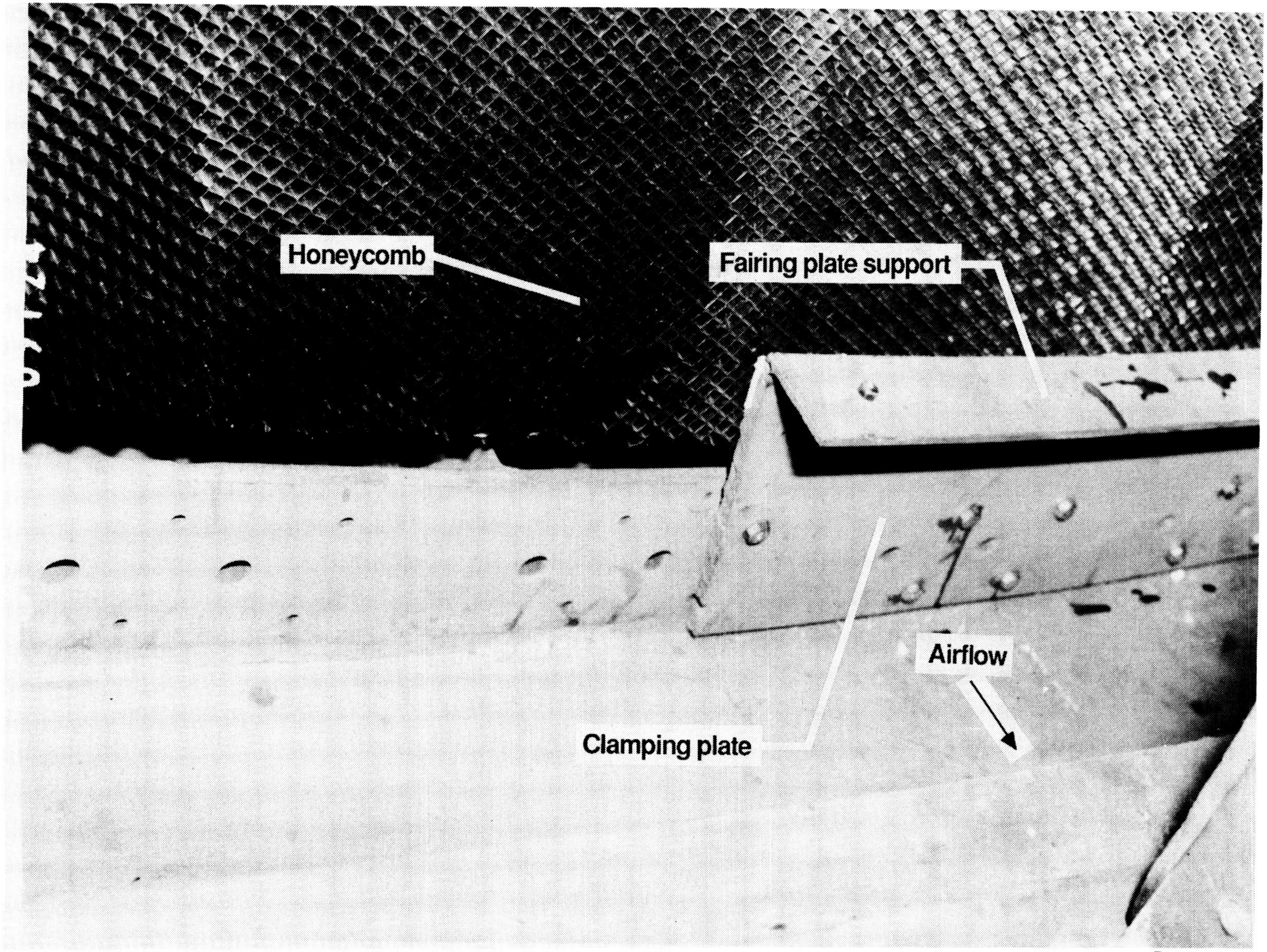
(b) Honeycomb panel at floor.

Figure 16. Continued.

L-81-8500

(c) Spot welding joints.

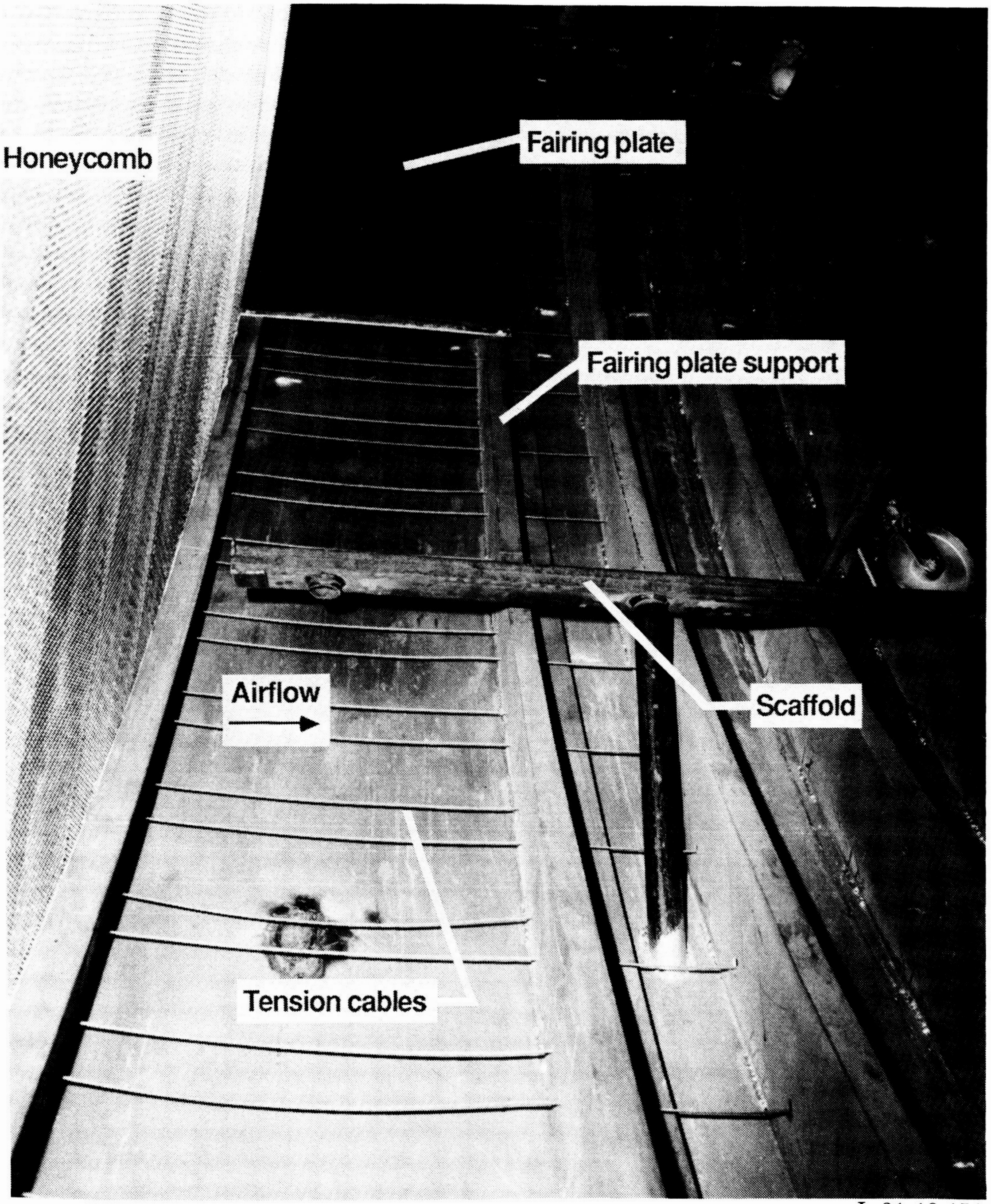
Figure 16. Continued.



L-81-9124

(d) Honeycomb and fairing plate support.

Figure 16. Concluded.



L-81-10,151

Figure 17. Screen tension cables and fairing plates immediately downstream of honeycomb.

L-82-644

Figure 18. Honeycomb lateral support cables.

L-82-646

Figure 18. Concluded.

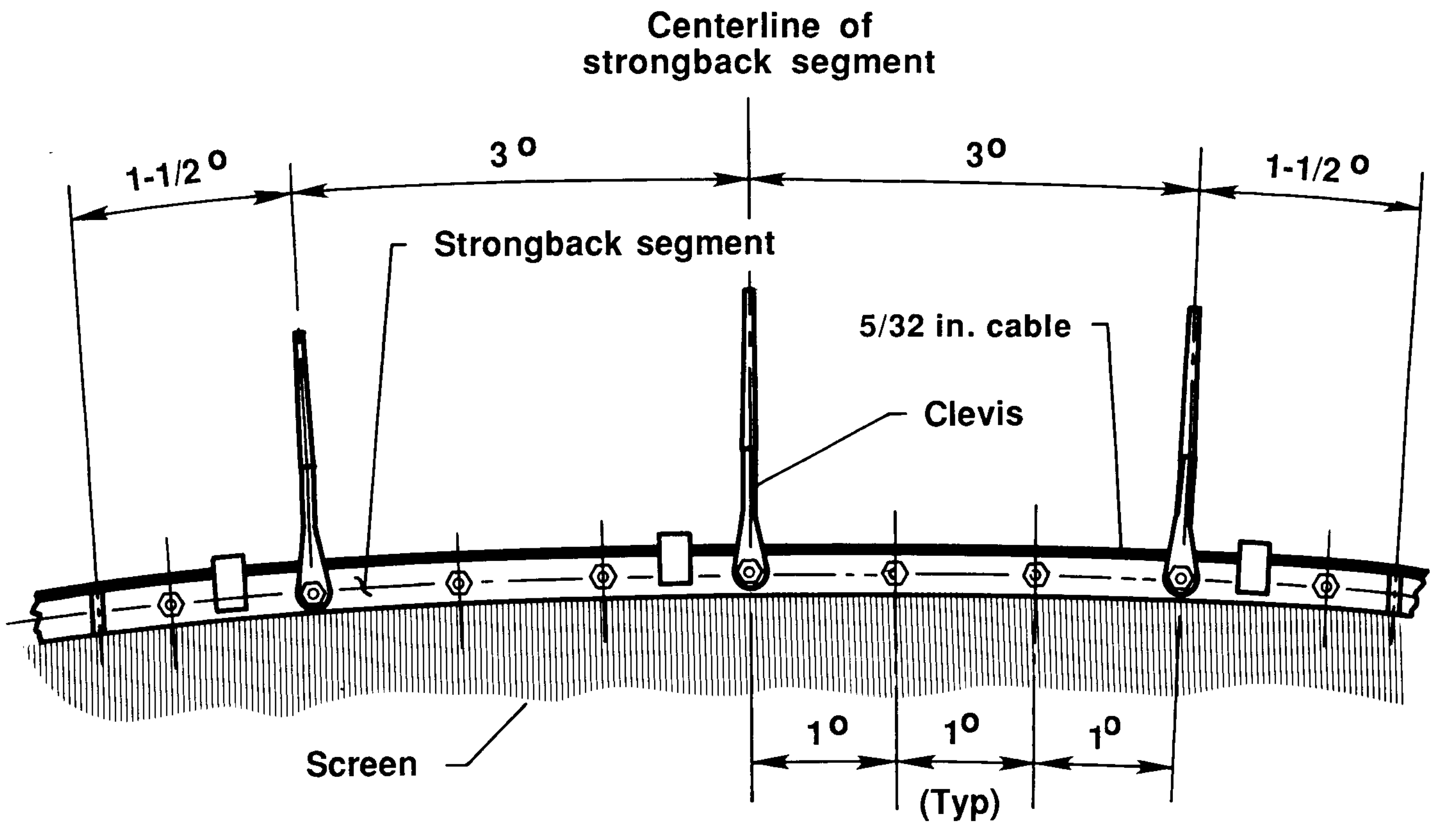


Figure 19. Sketches of screen perimeter details.

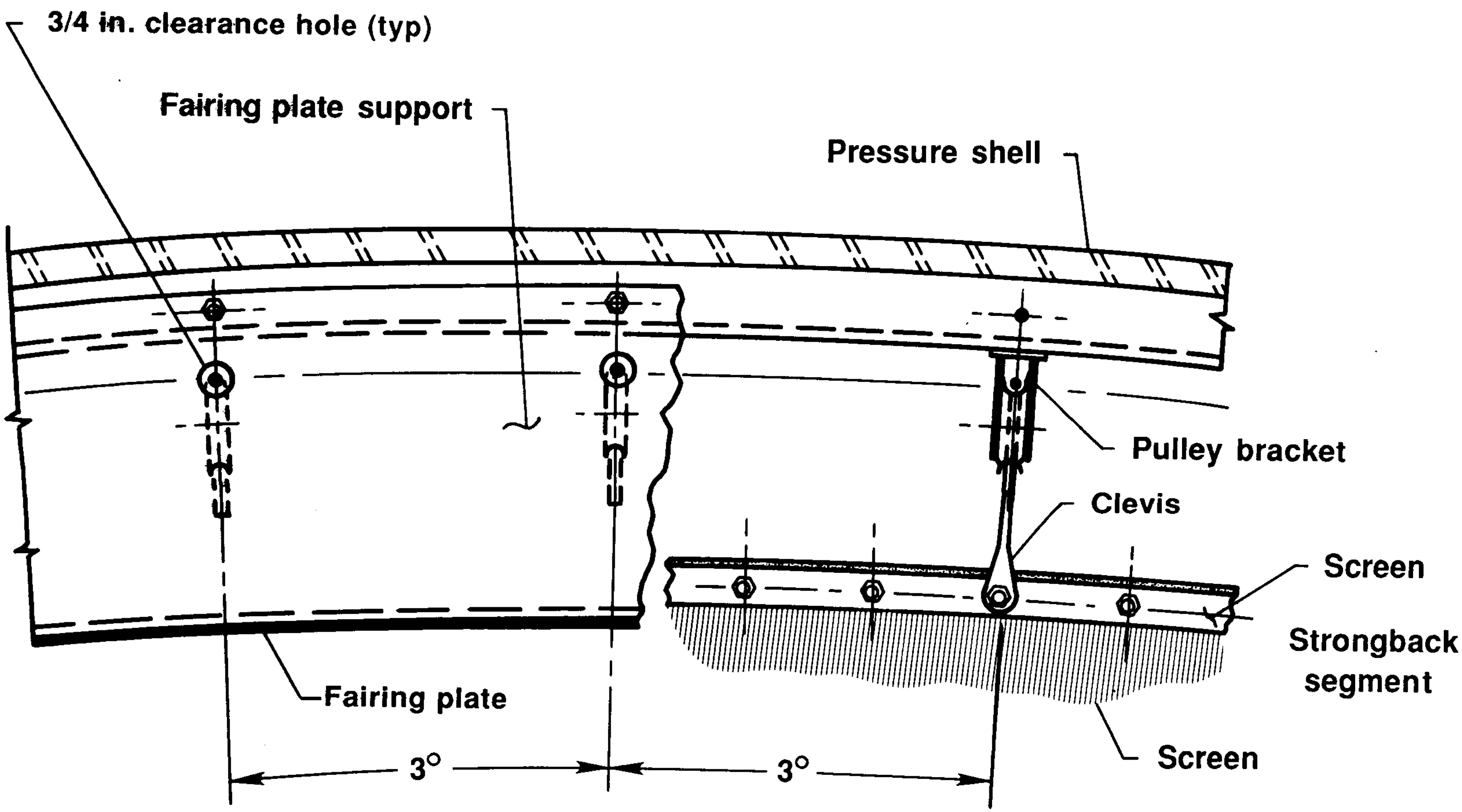


Figure 19. Continued.

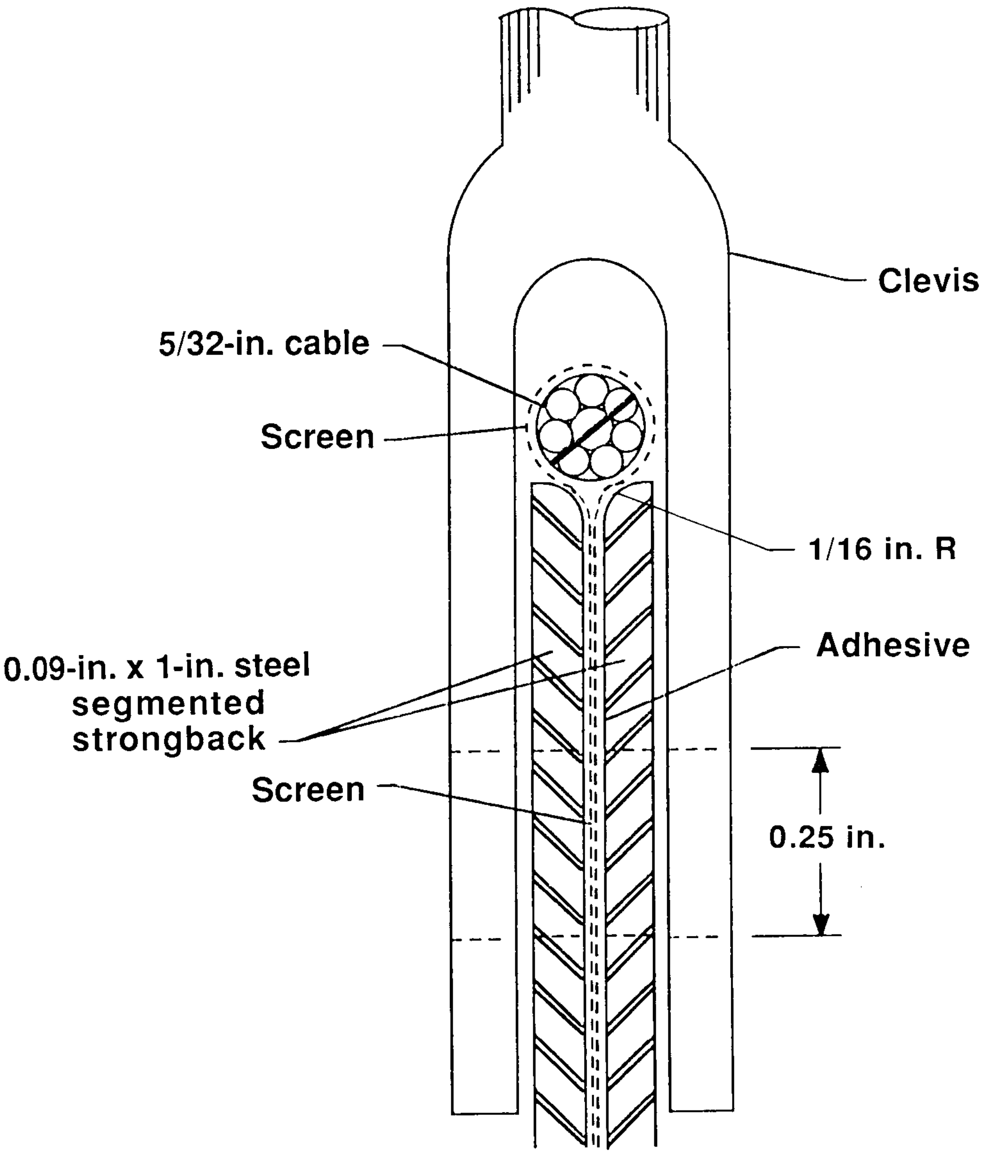


Figure 19. Concluded.

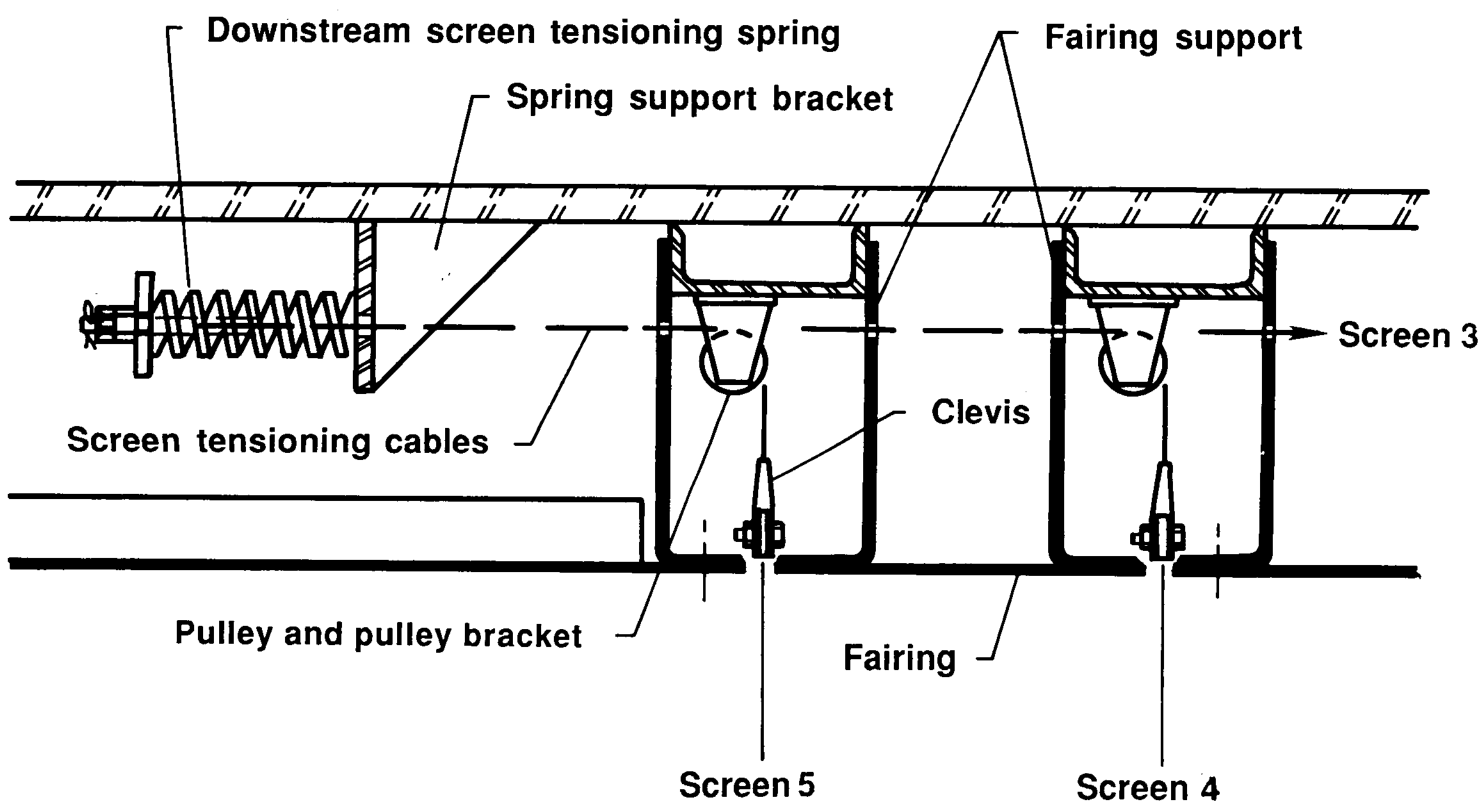


Figure 20. Sketch of screen support structure.

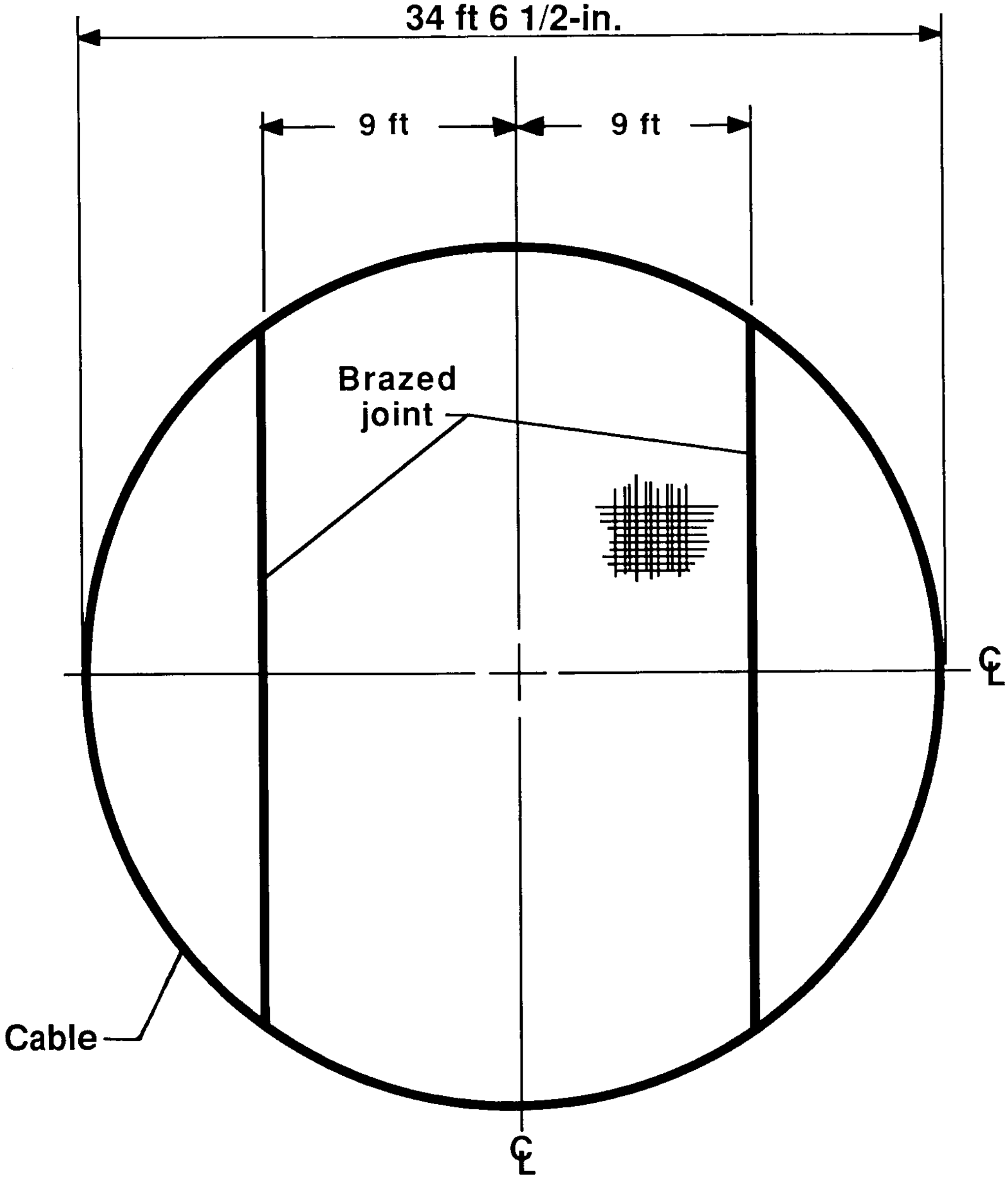


Figure 21. Location of screen brazed joints.

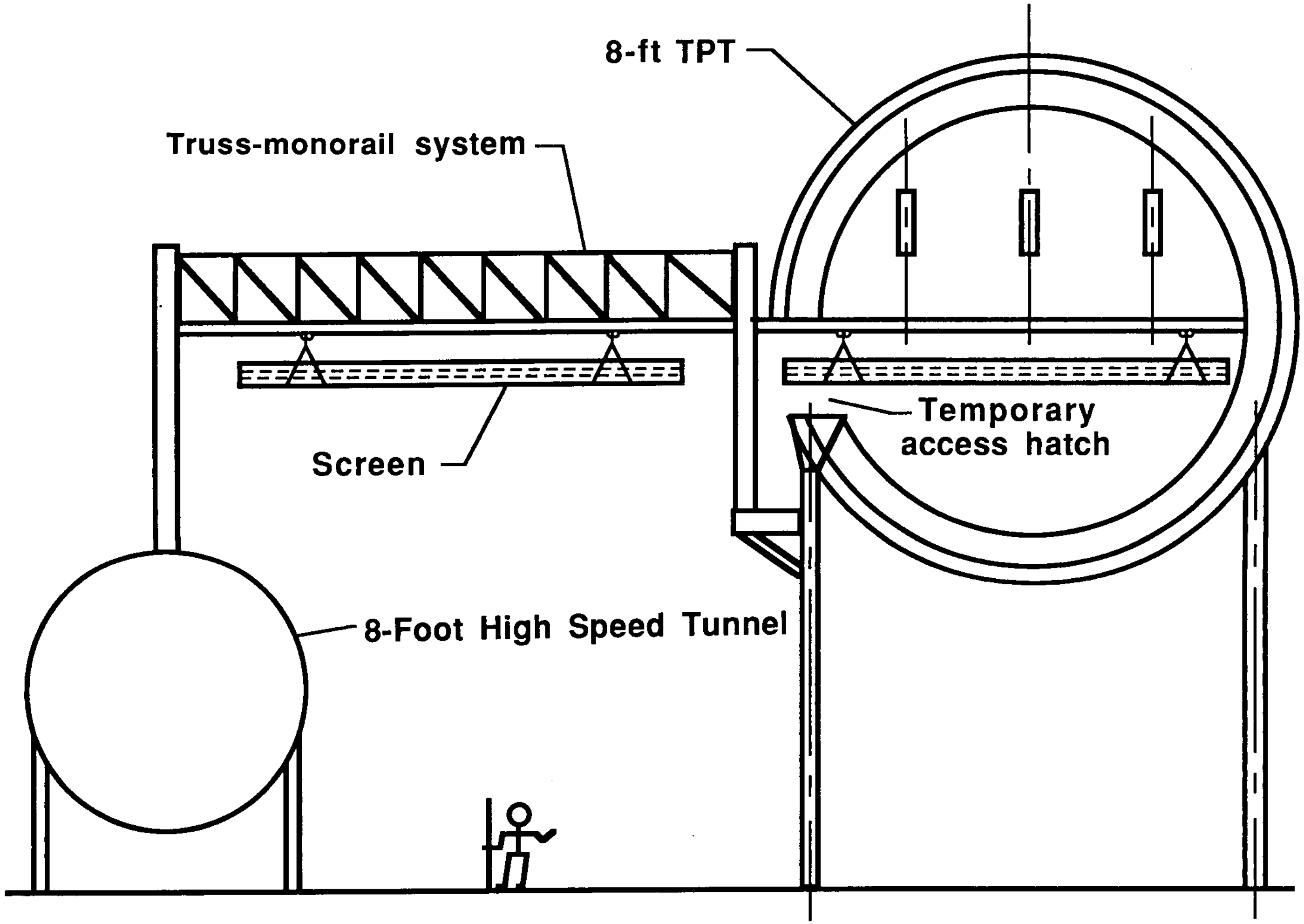
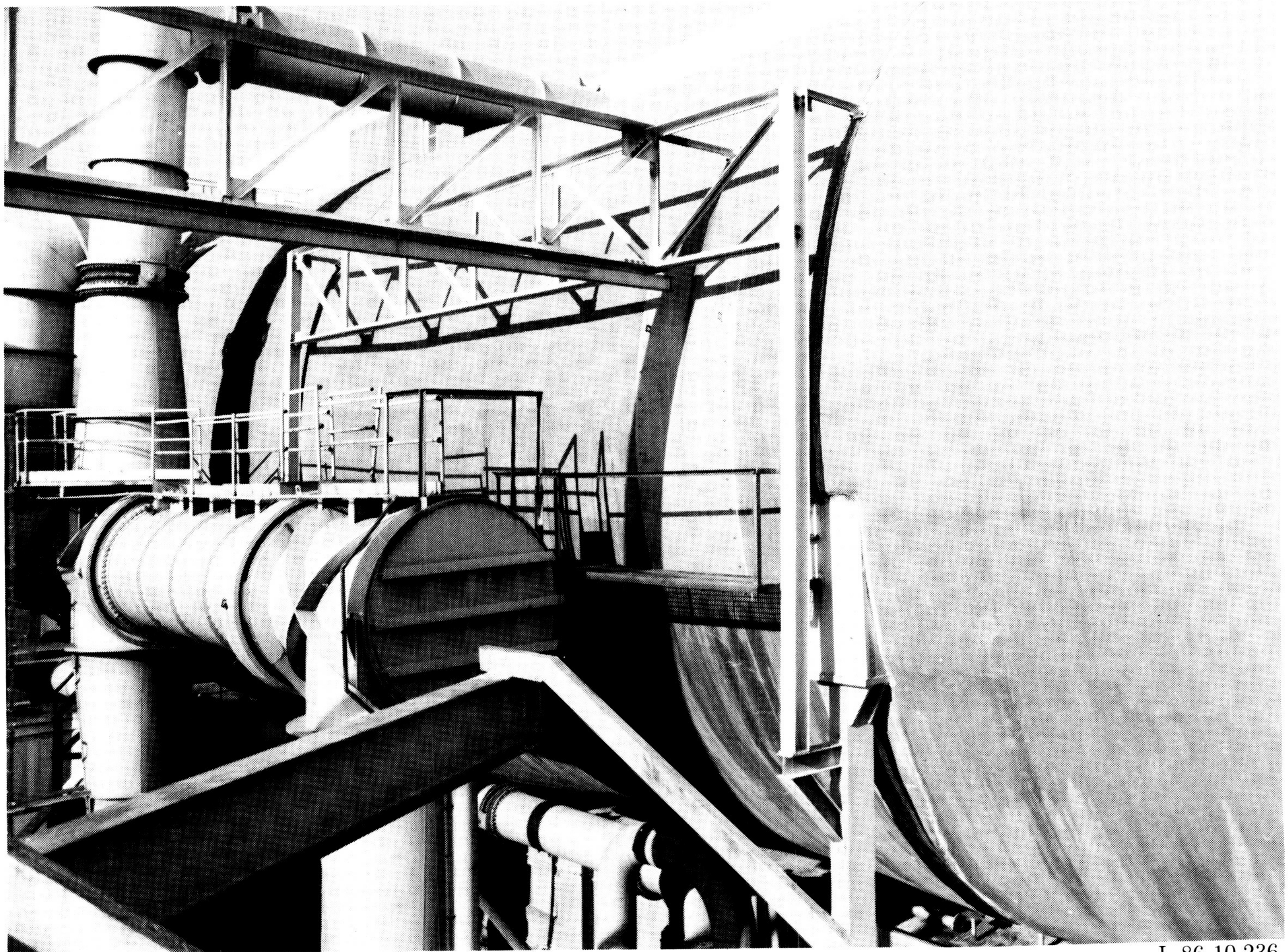


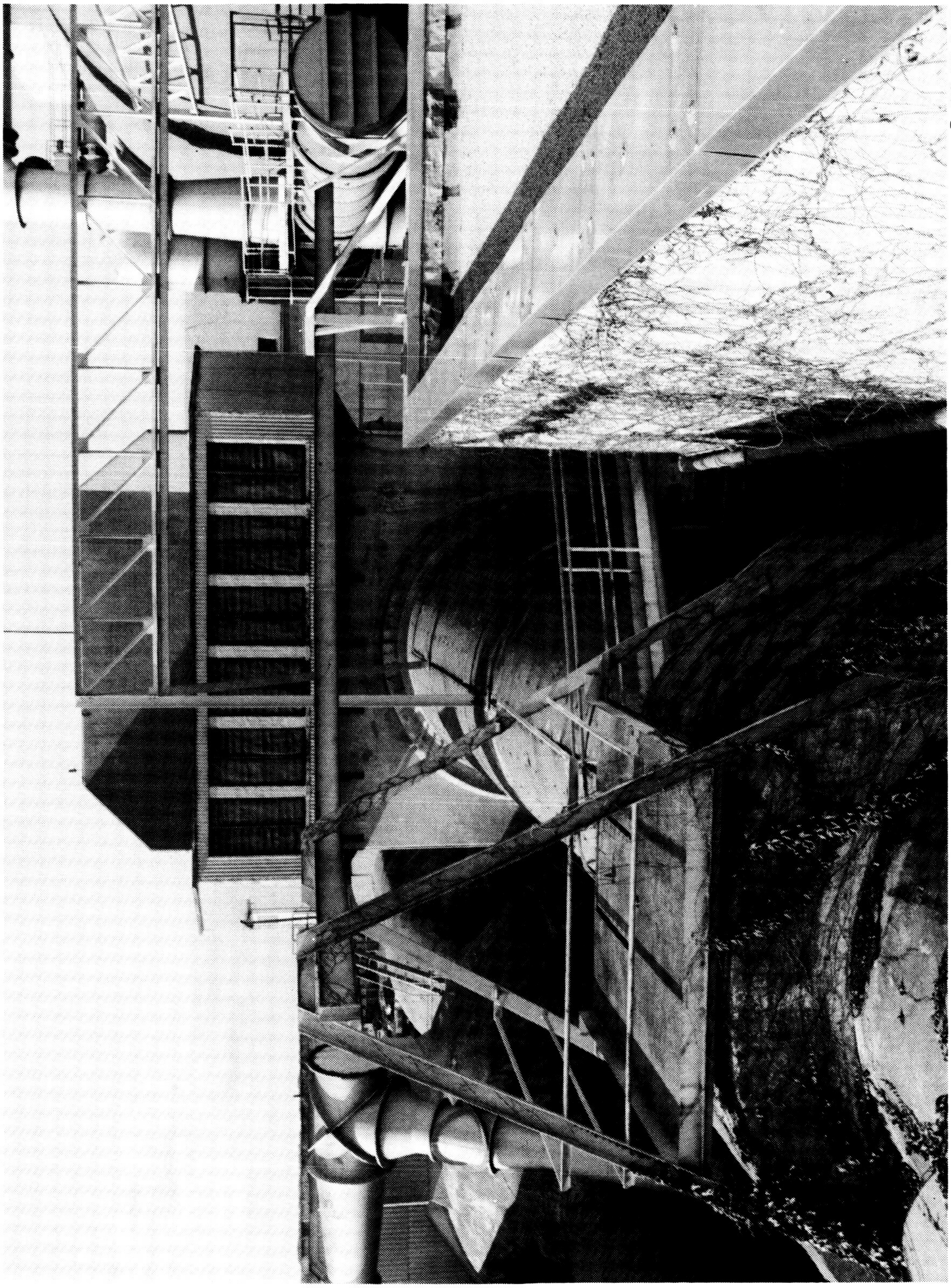
Figure 22. Sketch of monorail system.



L-86-10,236

(a) Monorail and access hatch.

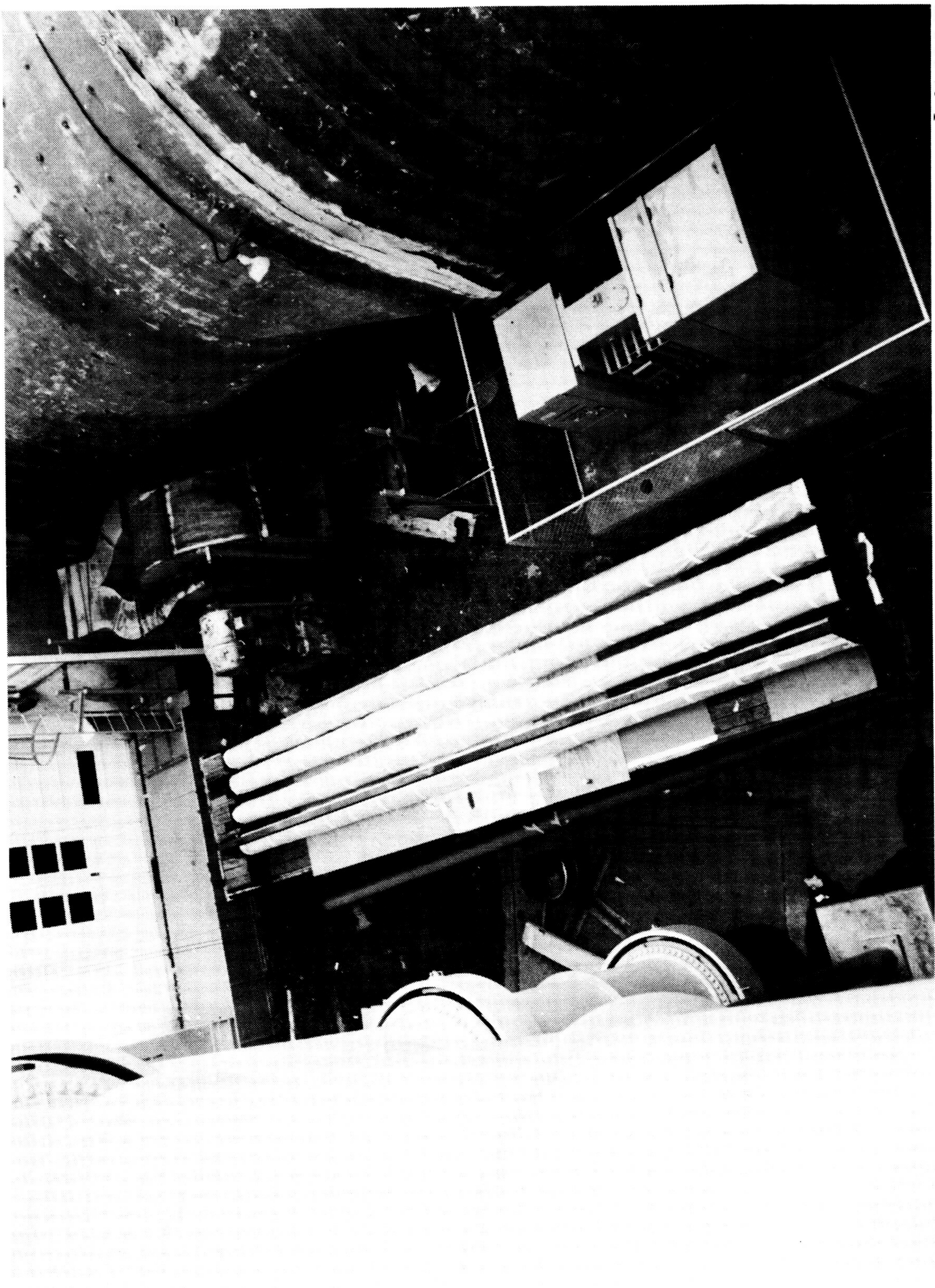
Figure 23. Monorail system and rolled screens.



L-86-10,266

(b) Monorail.

Figure 23. Continued.



L-81-11,047

(c) Rolled screens.

Figure 23. Concluded.

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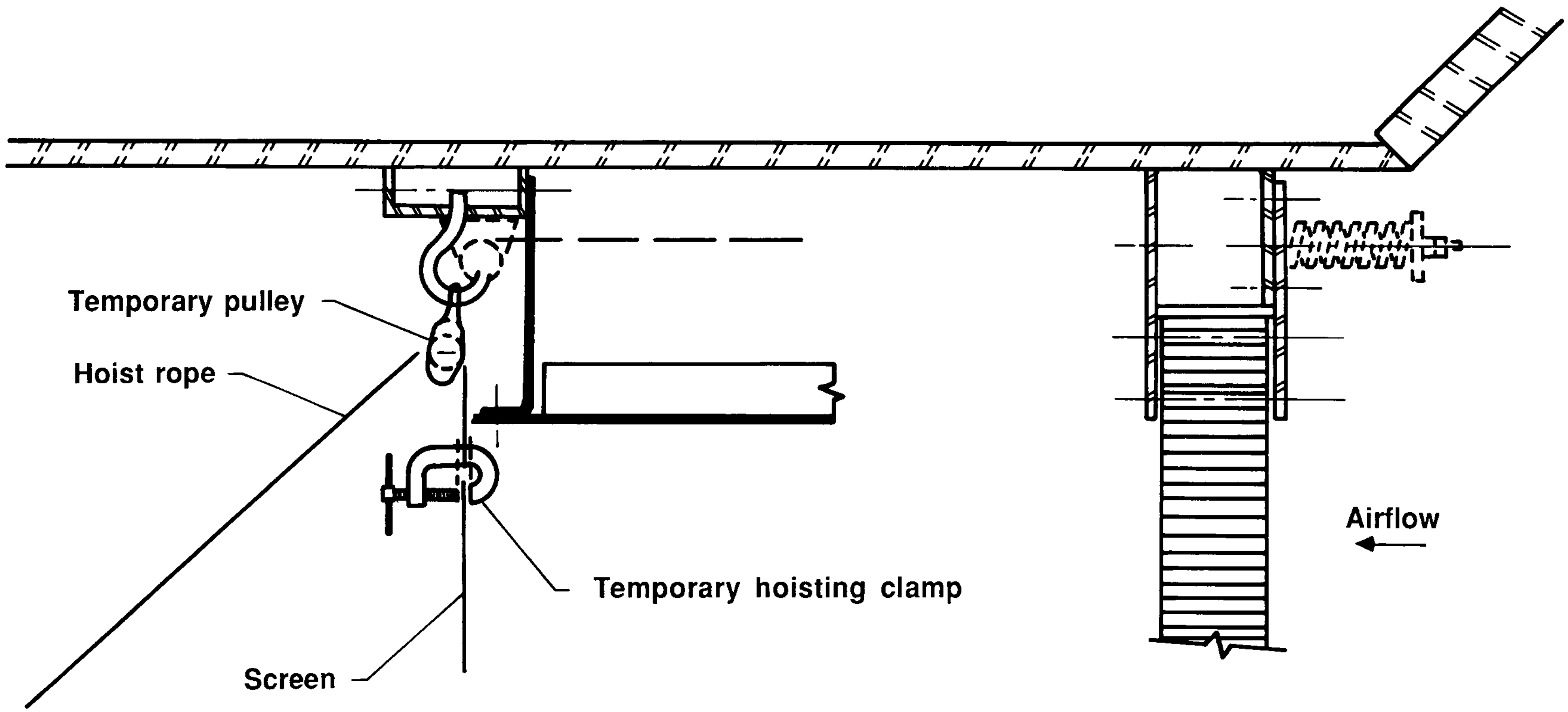
L-81-11,921

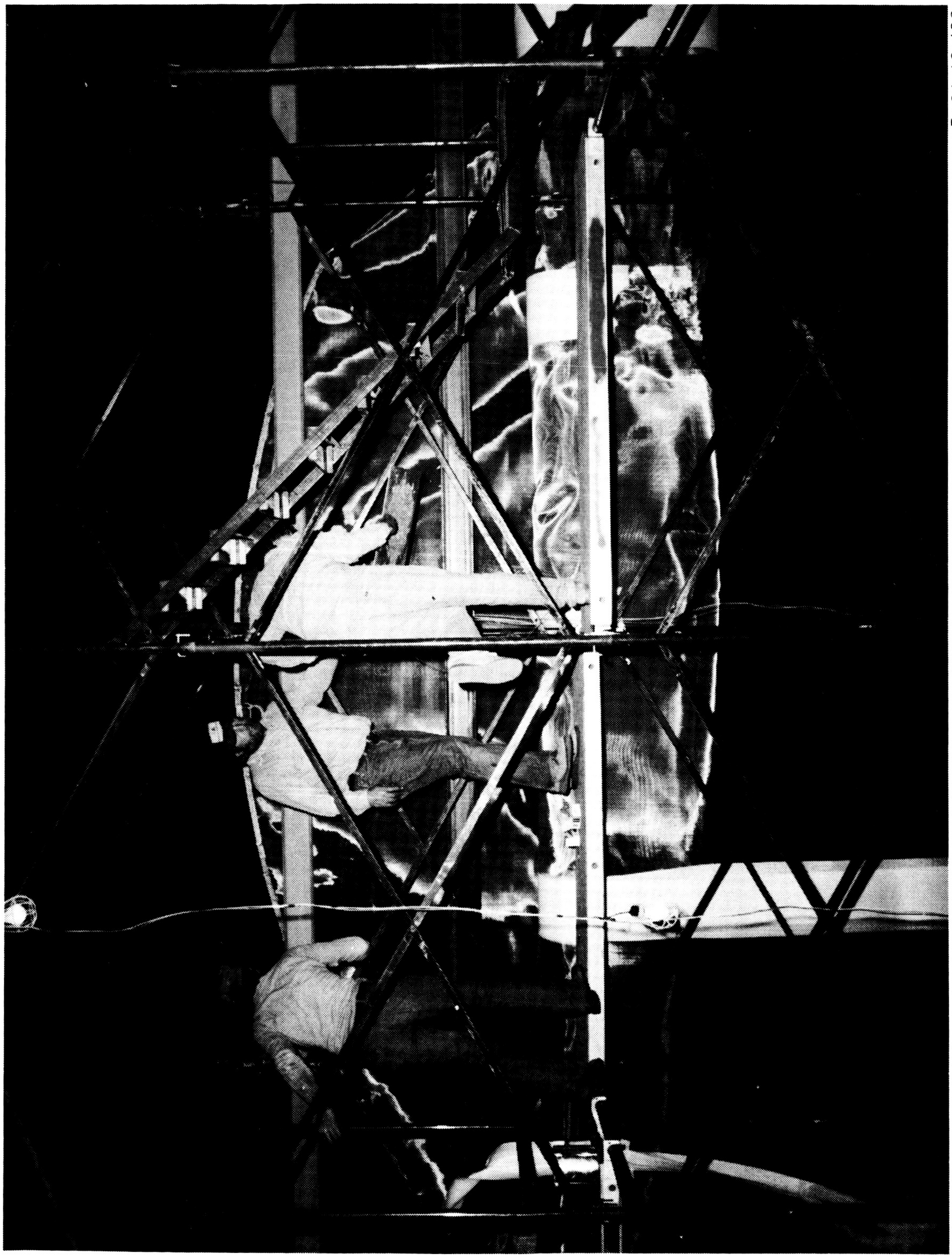
(a) Photograph of rolled screen in tunnel.

Figure 24. Photographs and sketch of screen installation.



(b) Sketch of temporary hoisting clamp.

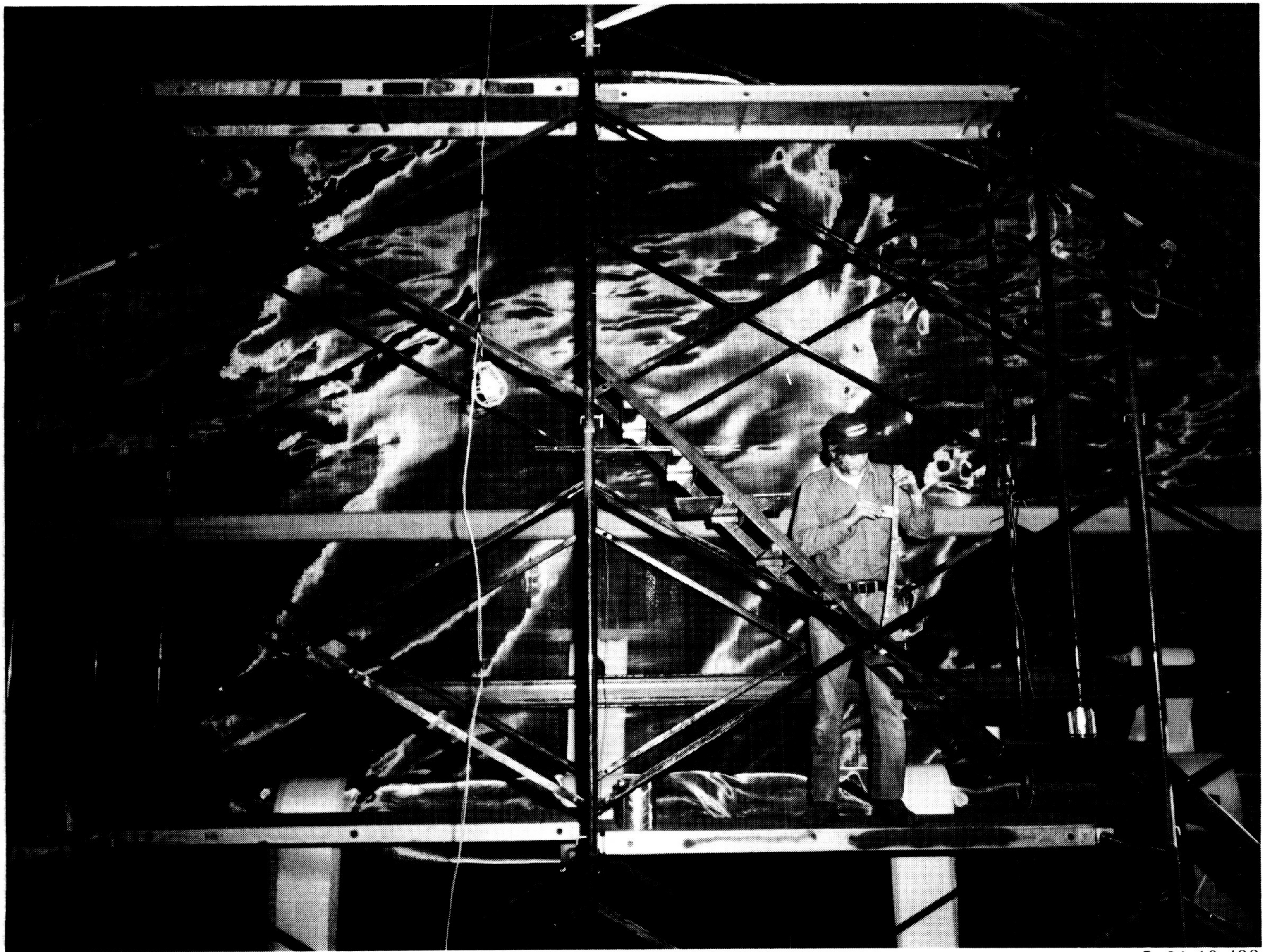
Figure 24. Continued.



L-81-10,498

(c) Hoisting of screen to top of tunnel.

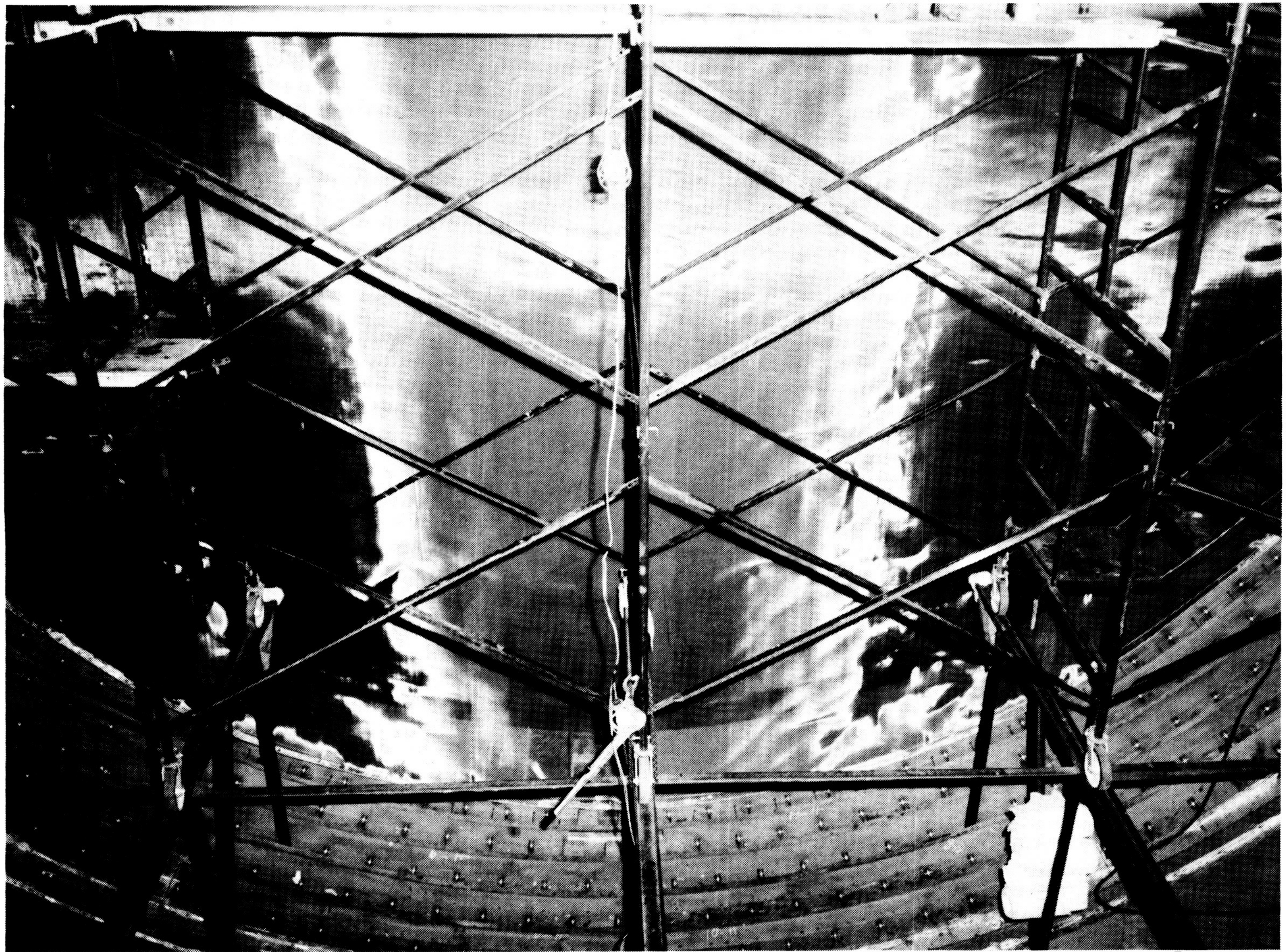
Figure 24. Continued.



L-81-10,499

(c) Continued.

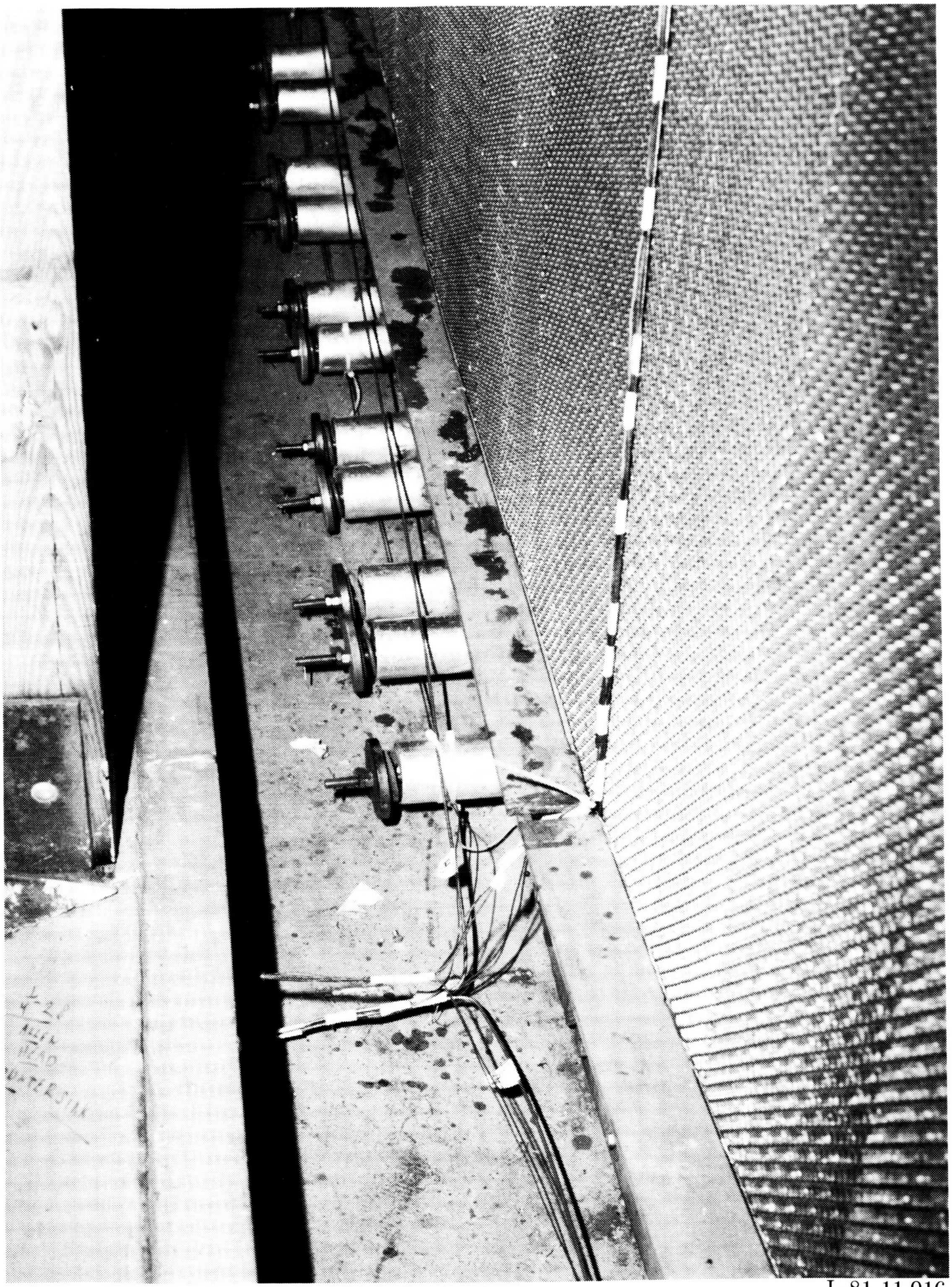
Figure 24. Continued.



L-81-1063

(c) Concluded.

Figure 24. Concluded.



L-81-11,916

Figure 25. Screen cable tensioning spring with sleeve.

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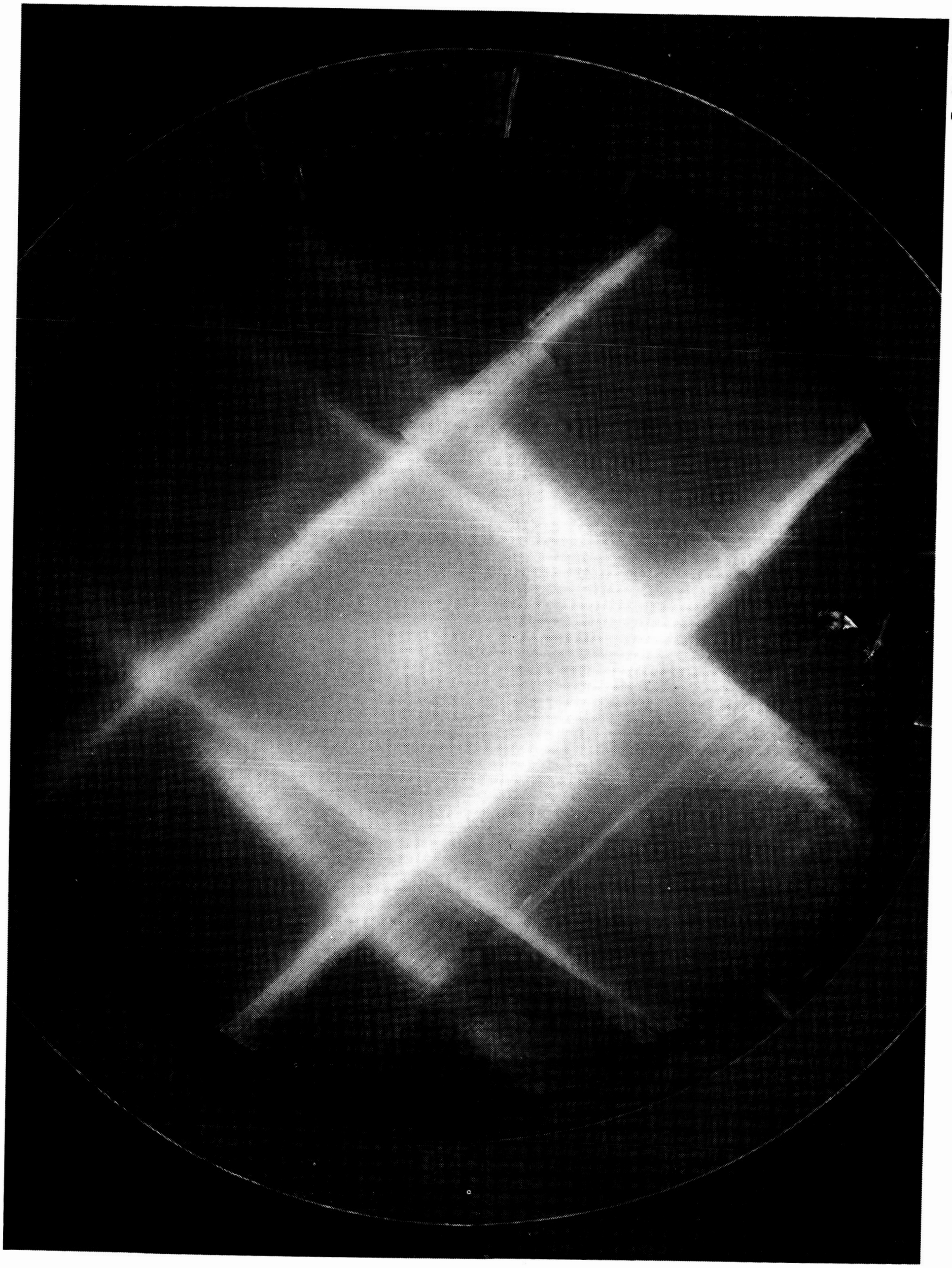
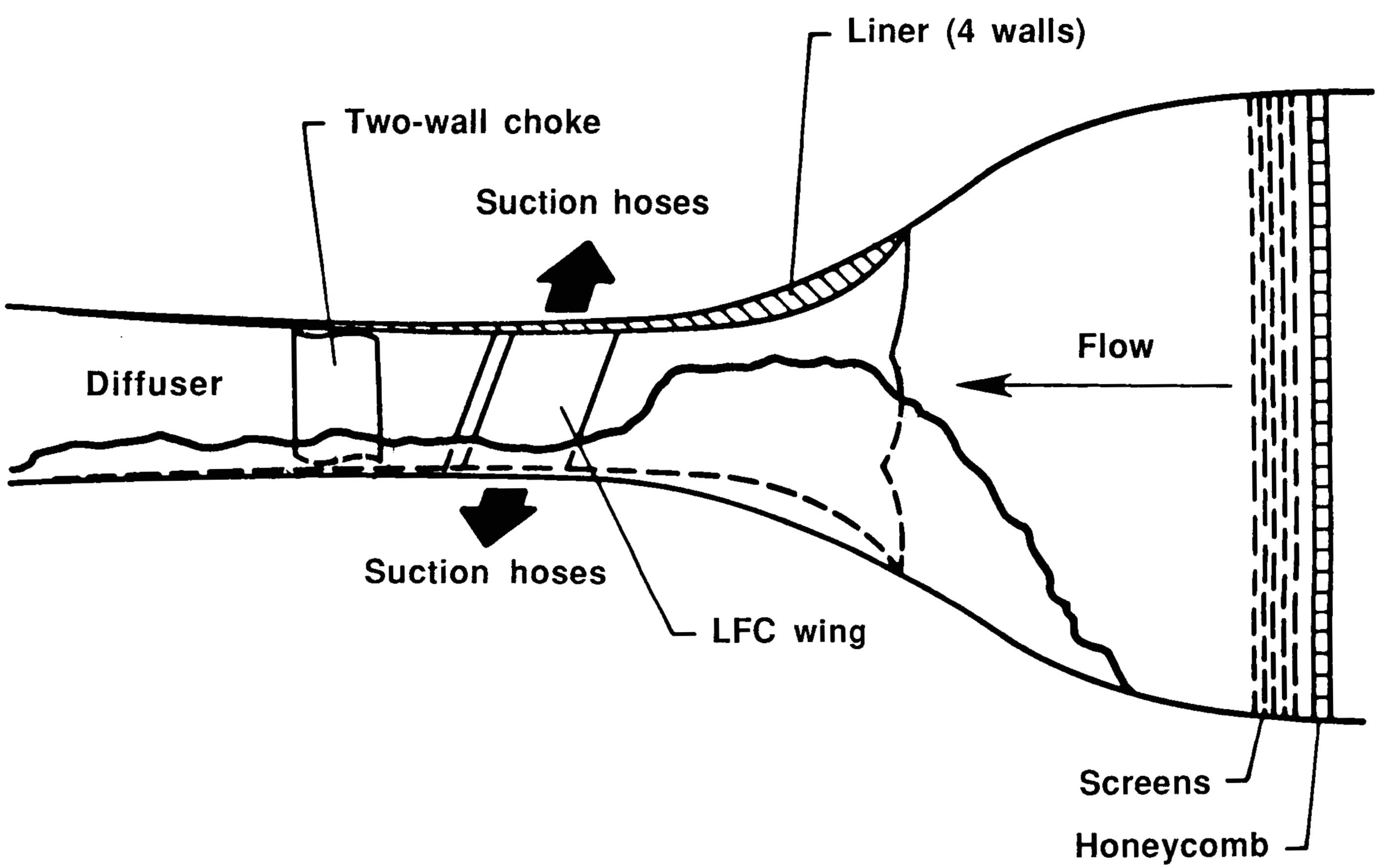


L-84-4065

Figure 26. Photograph of fifth screen after installation completed; view upstream from test section.

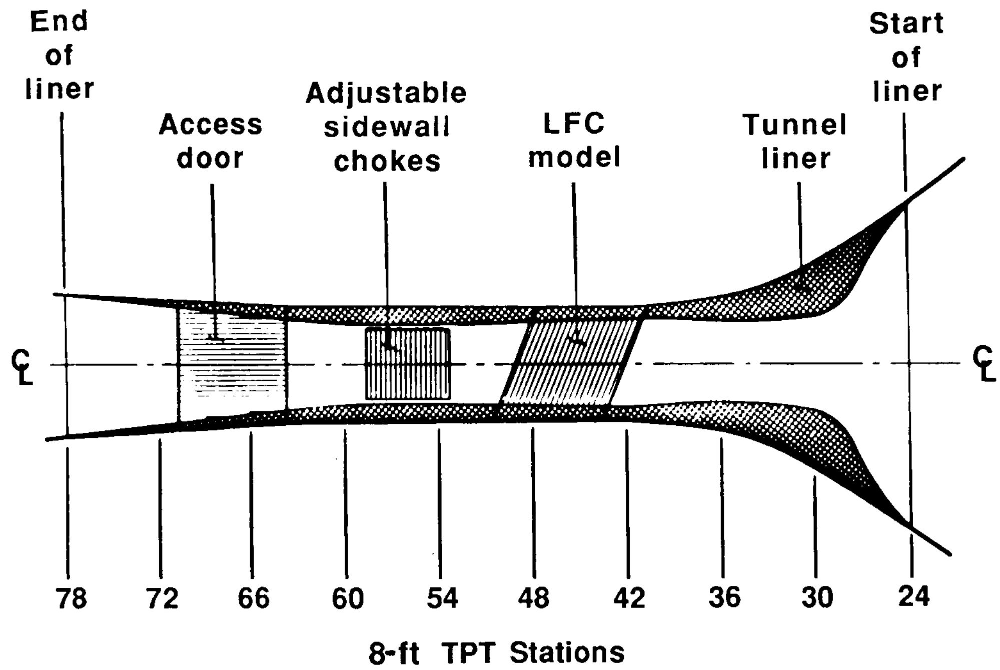
L-82-639

Figure 26. Concluded.



(a) General layout of liner and its location relative to honeycomb and screens.

Figure 27. Sketches of test section liner.



(b) Liner contours.

Figure 27. Concluded.

L-81-5106

(a) Upstream view of east wall from test section door.

Figure 28. Photographs during removal of conventional hardware from test section.

L-81-5101

(b) Removal of test section corner fillet.

Figure 28. Continued.

L-81-5108

(c) Upstream view during test section fillet removal process.

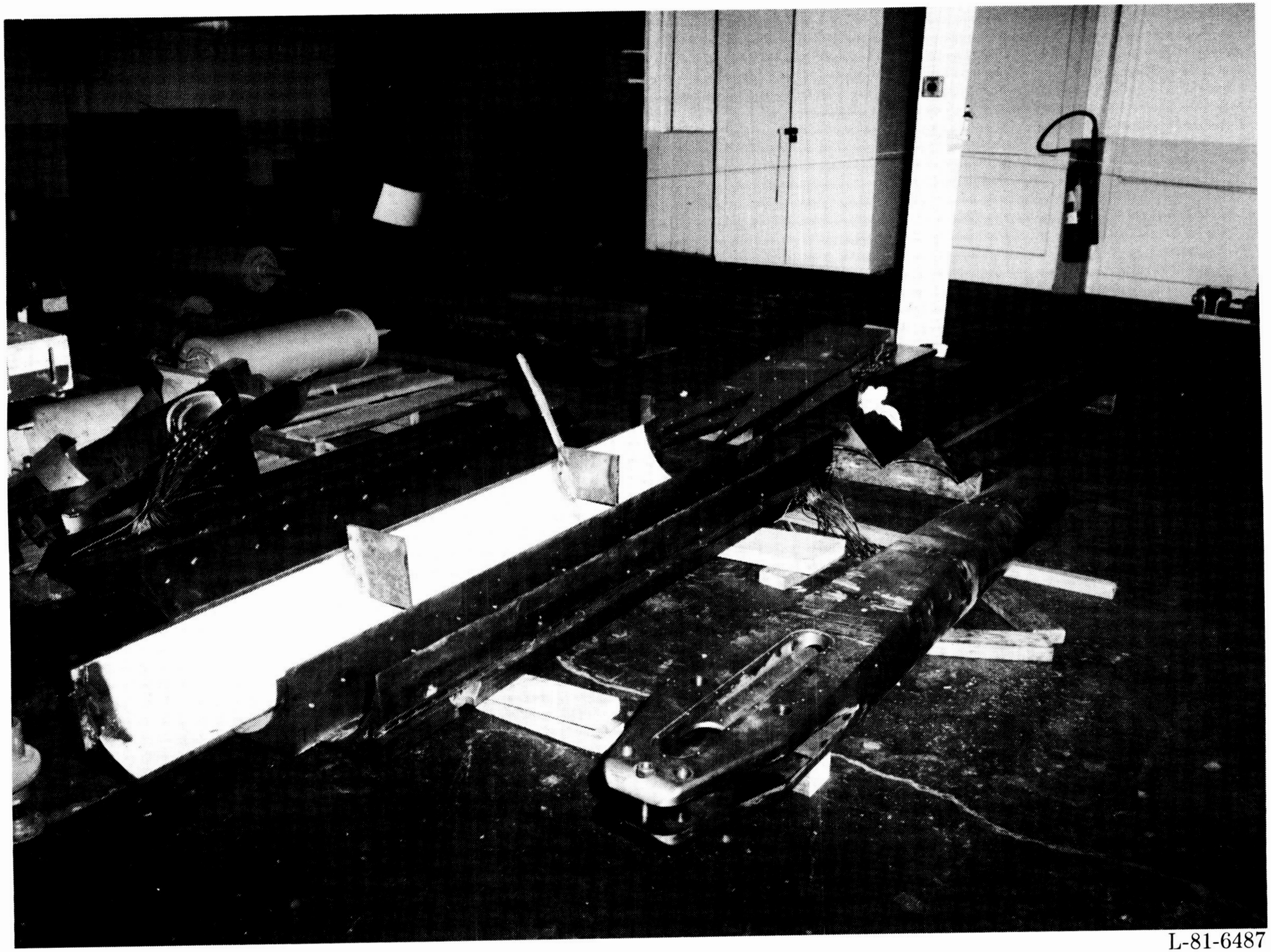
Figure 28. Concluded.

L-81-5542

Figure 29. Holes burned in ceiling of test section for model suction hoses and instrumentation.

L-81-5543

Figure 29. Concluded.



L-81-6487

Figure 30. Conventional hardware on floor of storage area after being removed from test section.

L-81-6486

Figure 30. Concluded.

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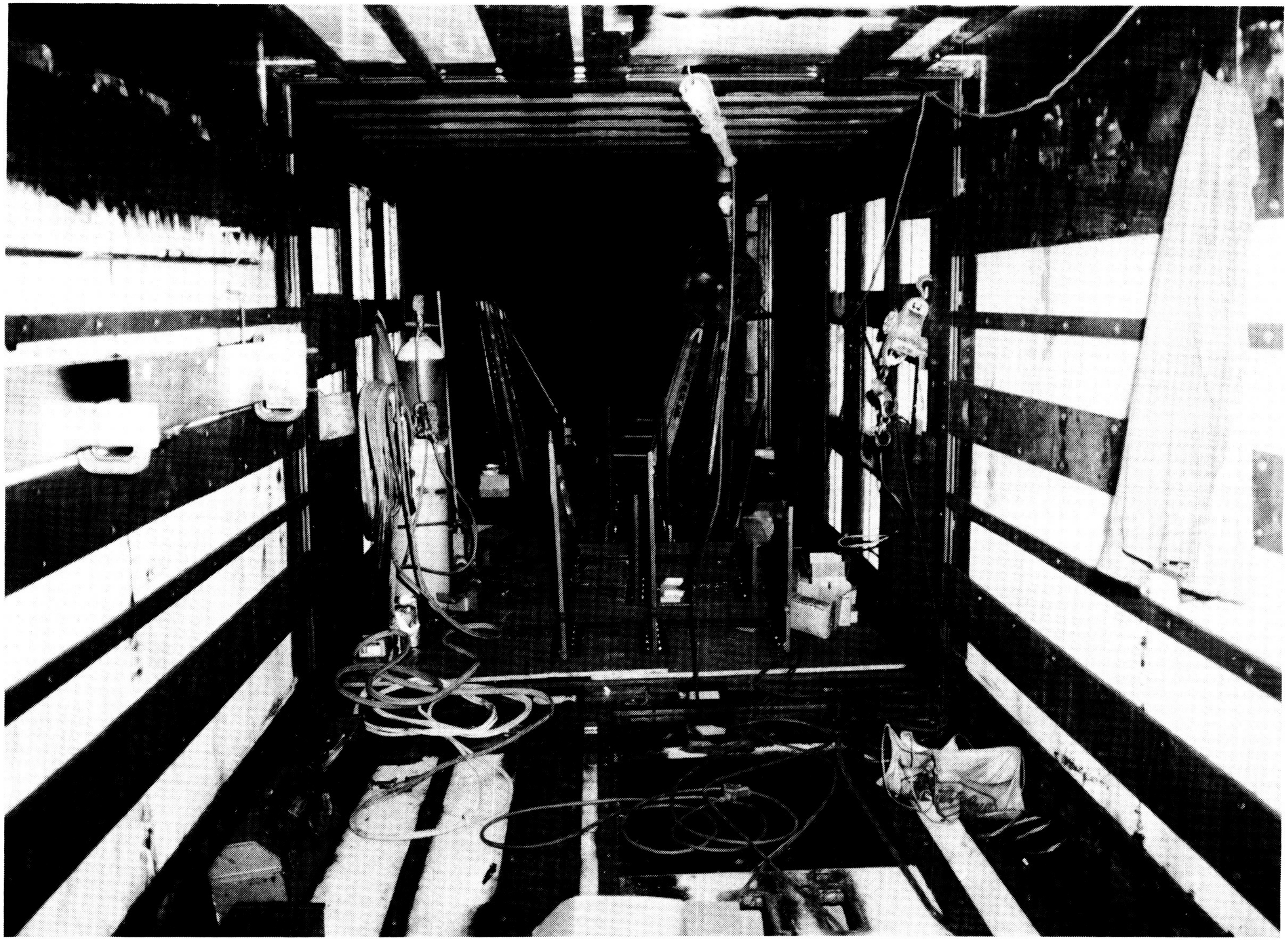
(a) Upstream view of east wall from test section access door.

Figure 31. Liner substructure during various stages of installation.



L-81-7995

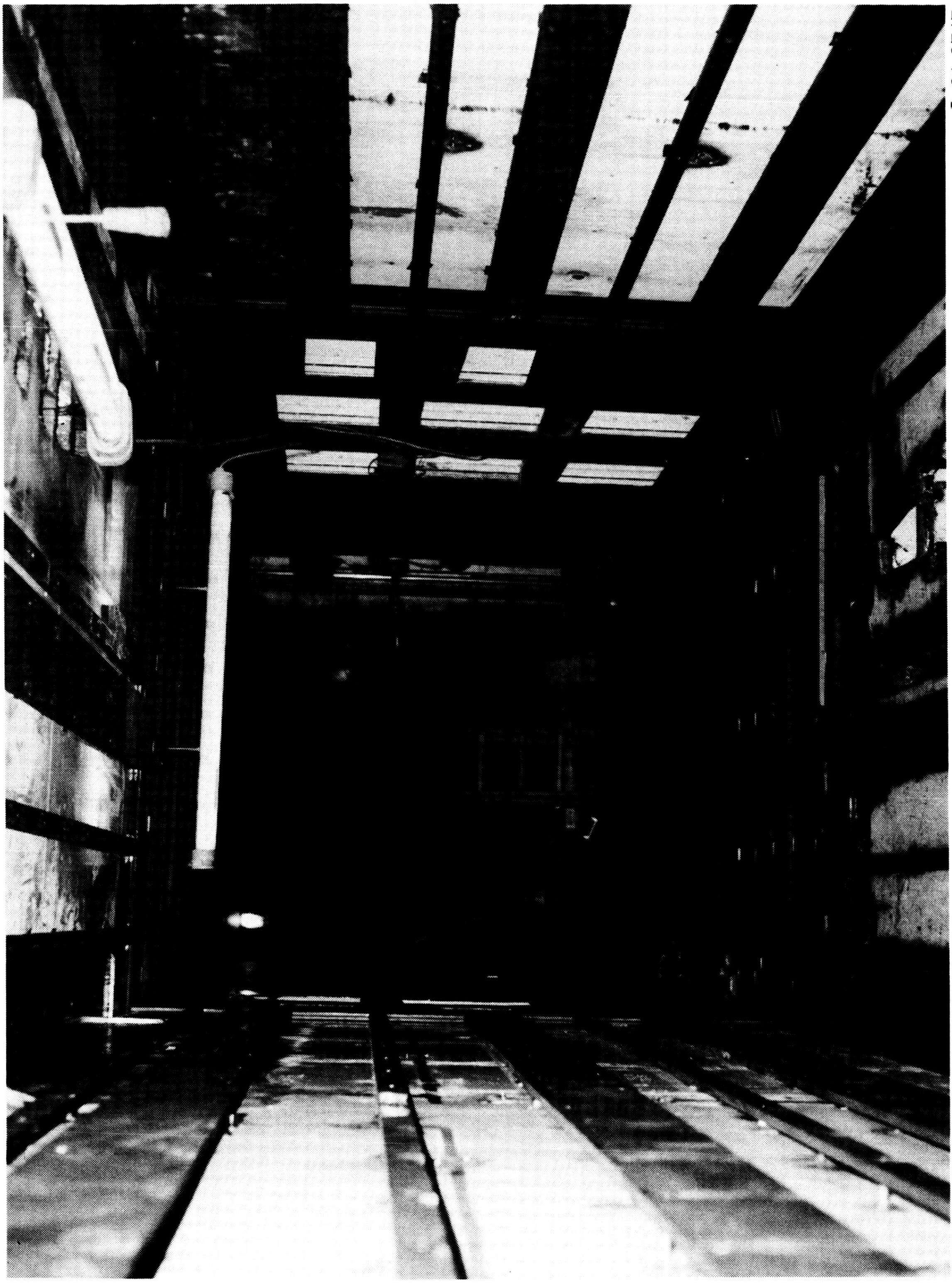
(c) Downstream view of test section.

Figure 31. Continued.

L-81-11,414

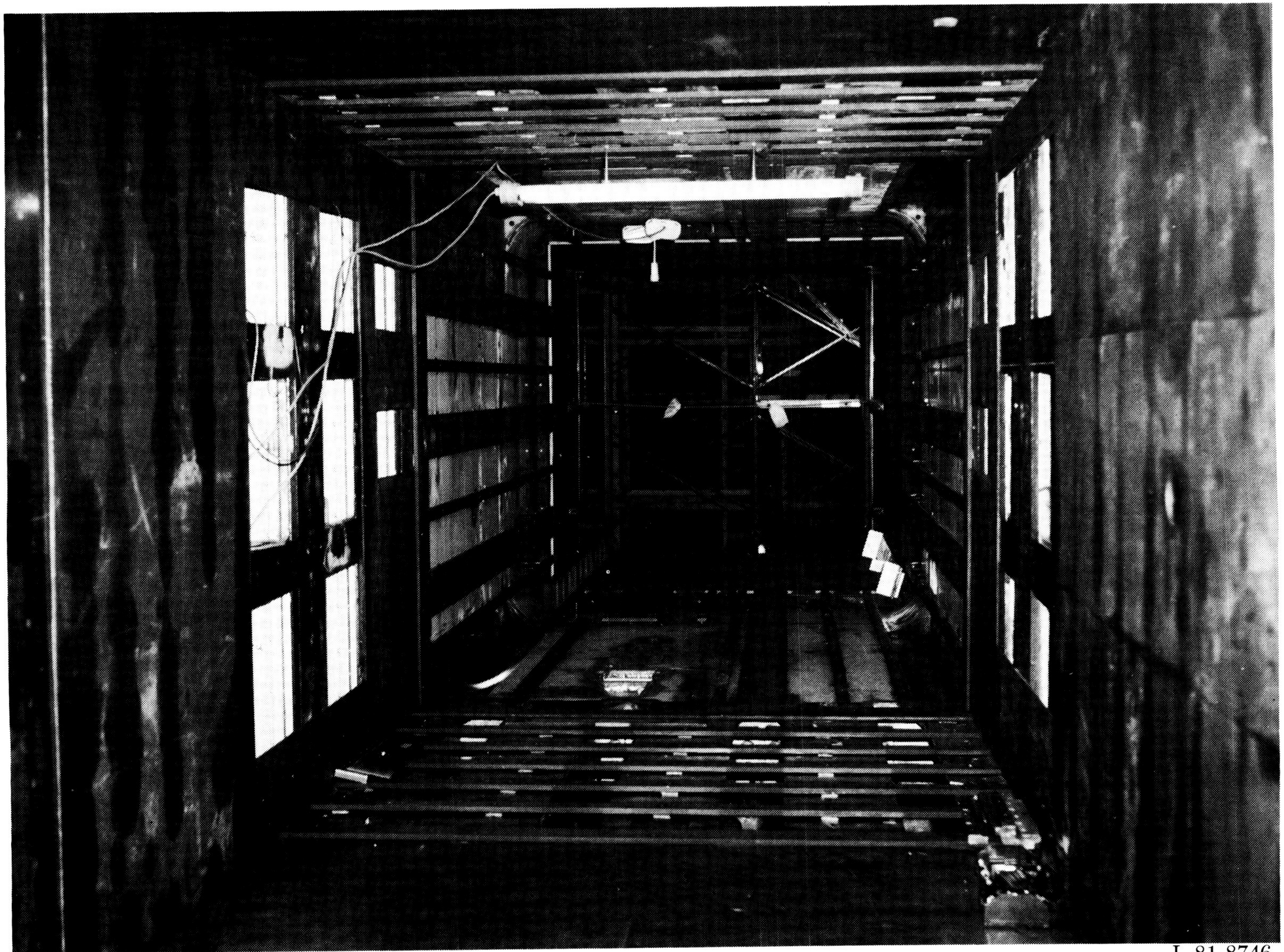
(b) Upstream view of east wall.

Figure 31. Continued.



(d) Downstream view of test section.

Figure 31. Continued.



L-81-8746

(e) Upstream view of test section.

Figure 31. Continued.

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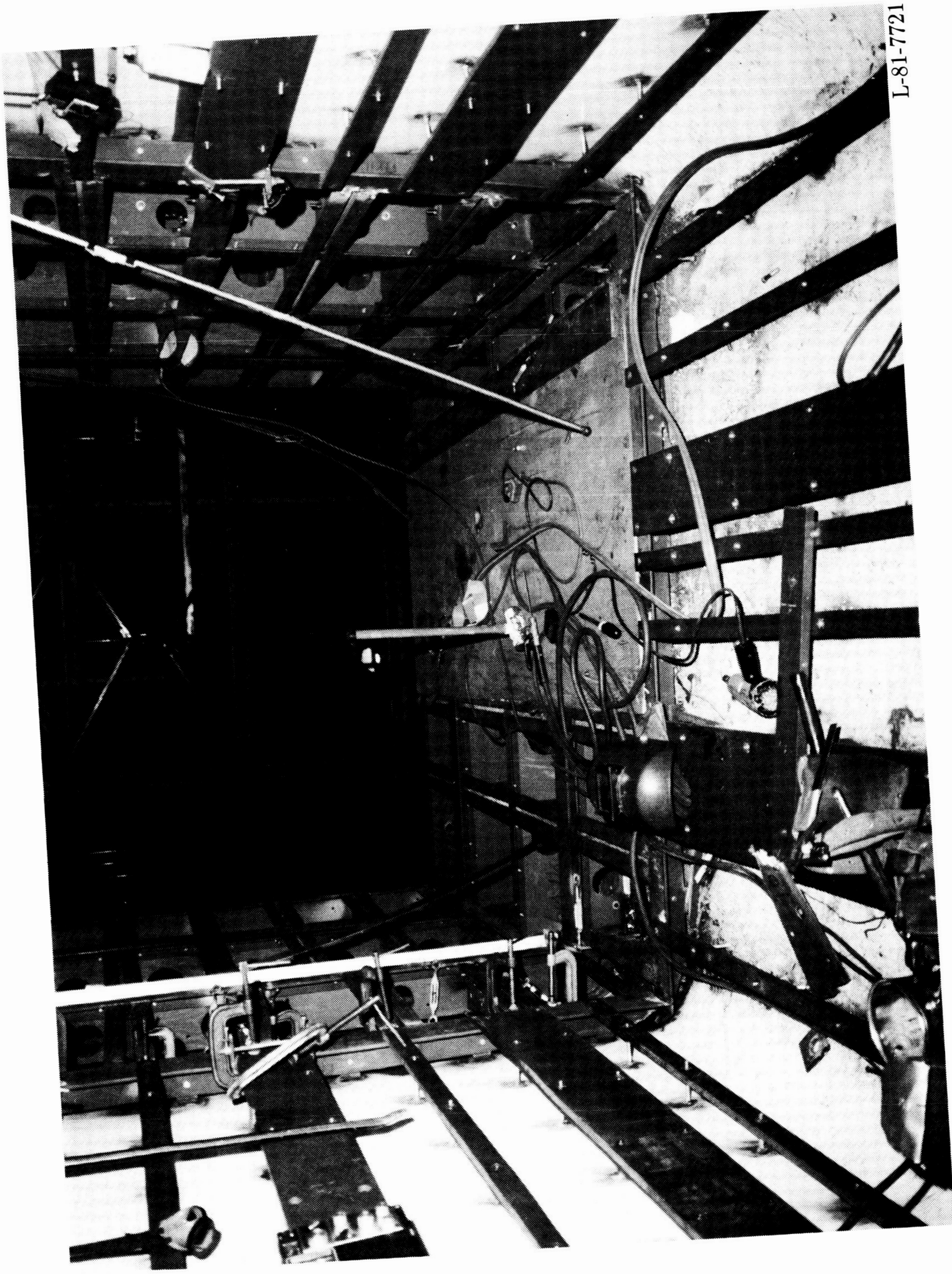


(f) Upstream view of test section.

Figure 31. Continued.

L-81-7593

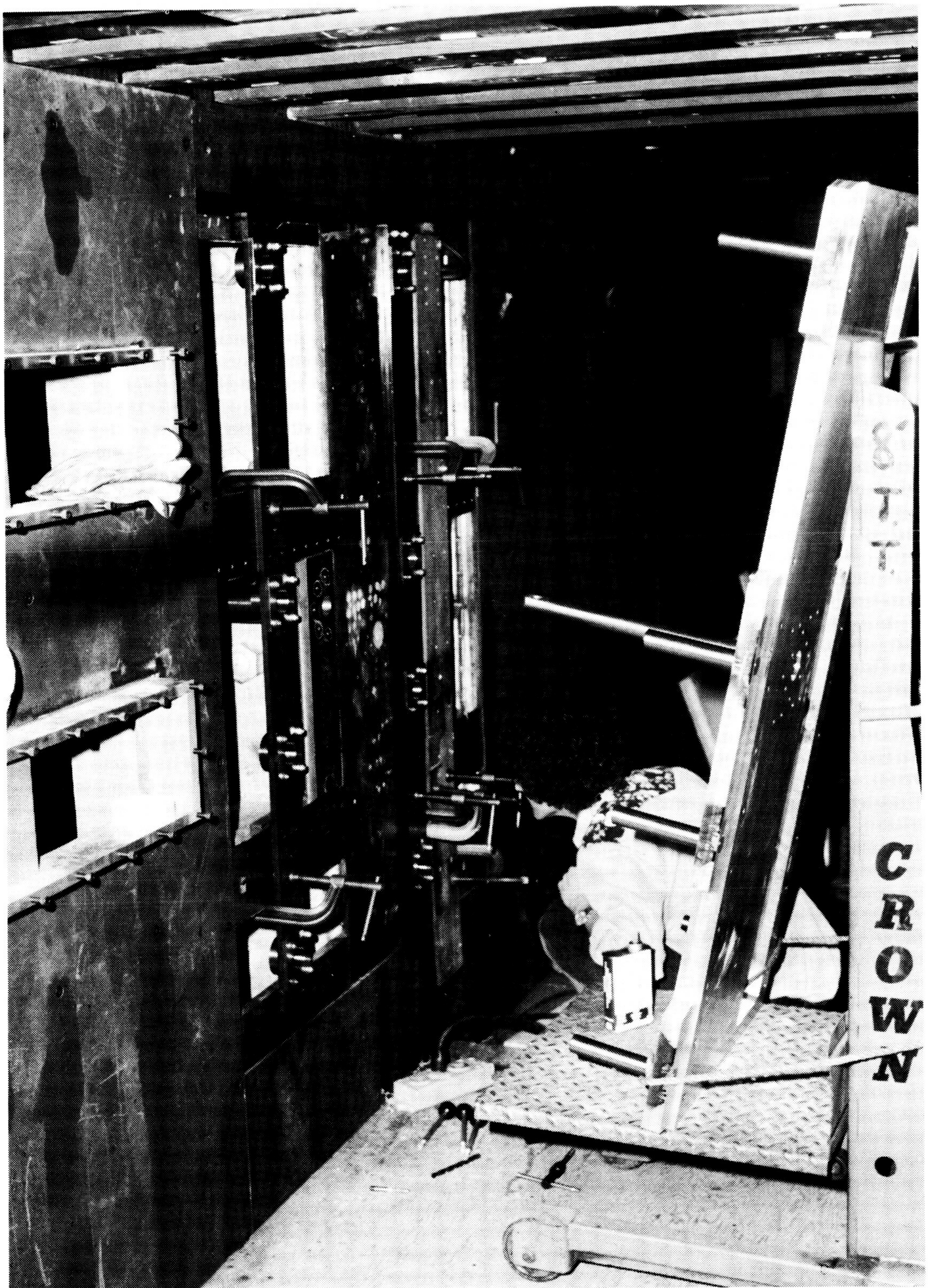
(g) Downstream view of east wall.

Figure 31. Continued.

L-81-9484

(h) Downstream view of east wall during installation of window frames.

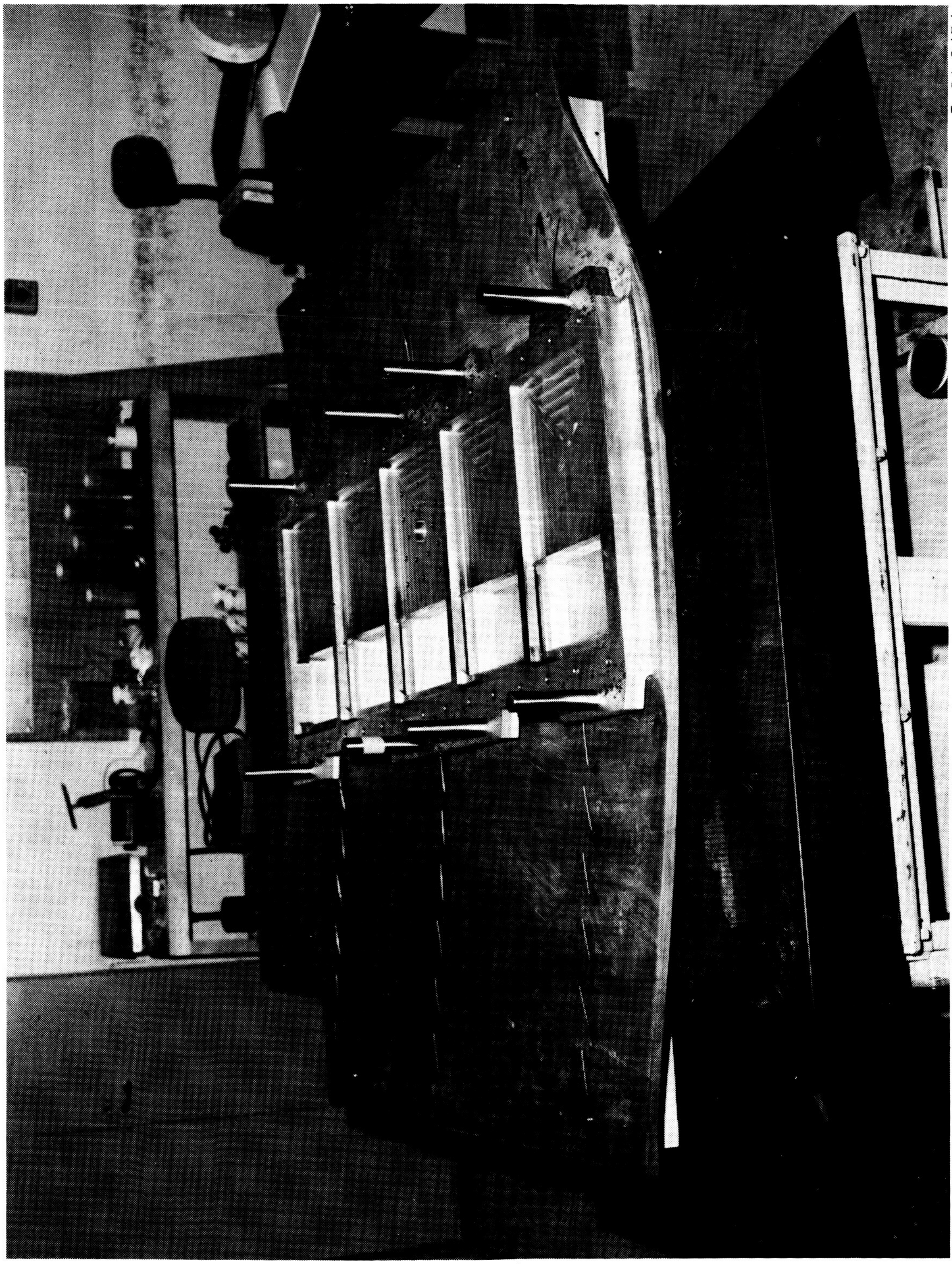
Figure 31. Continued.



L-81-9809

(i) Downstream view of east wall during installation of choke plate hardware.

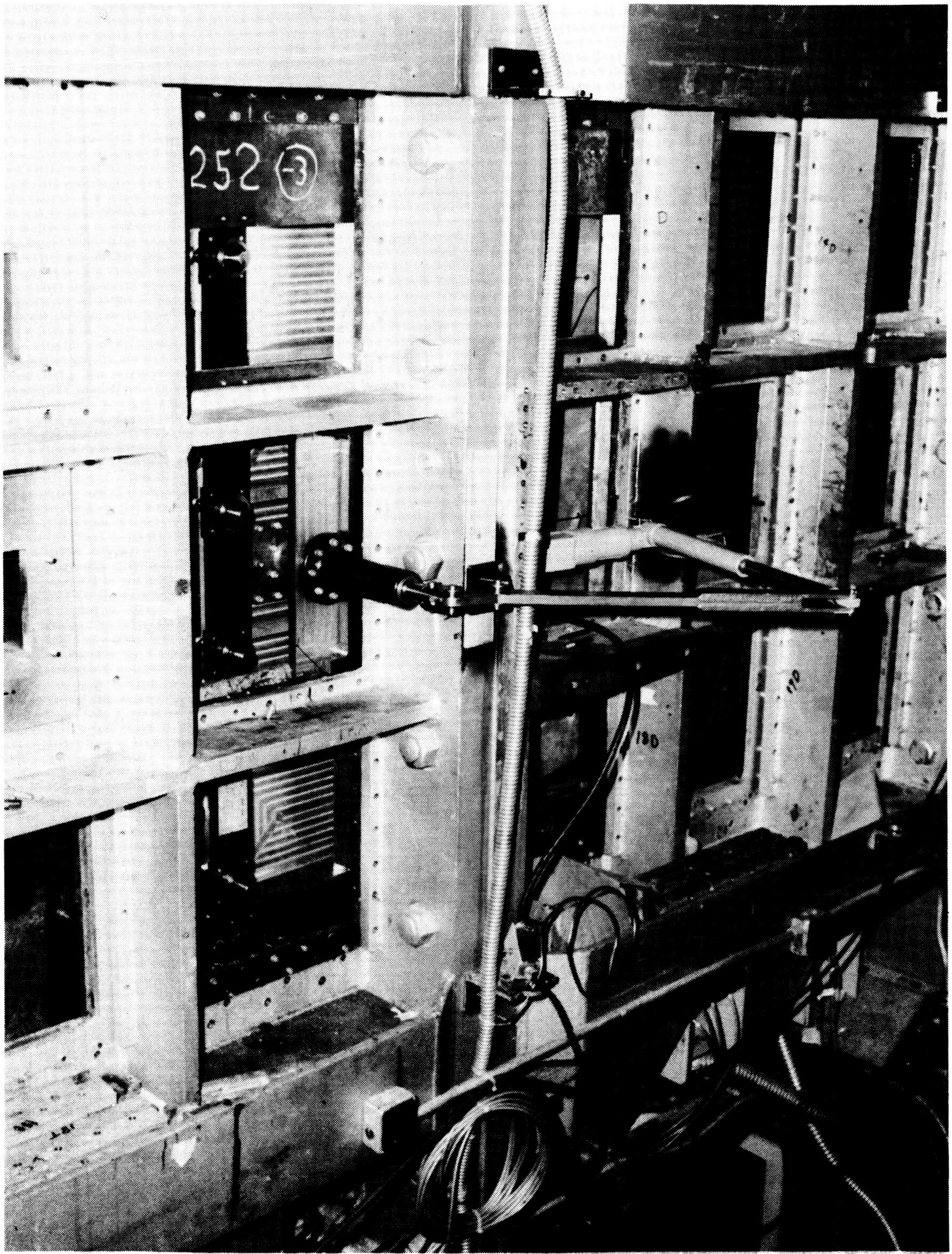
Figure 31. Continued.



L-81-9454

(j) Choke plate.

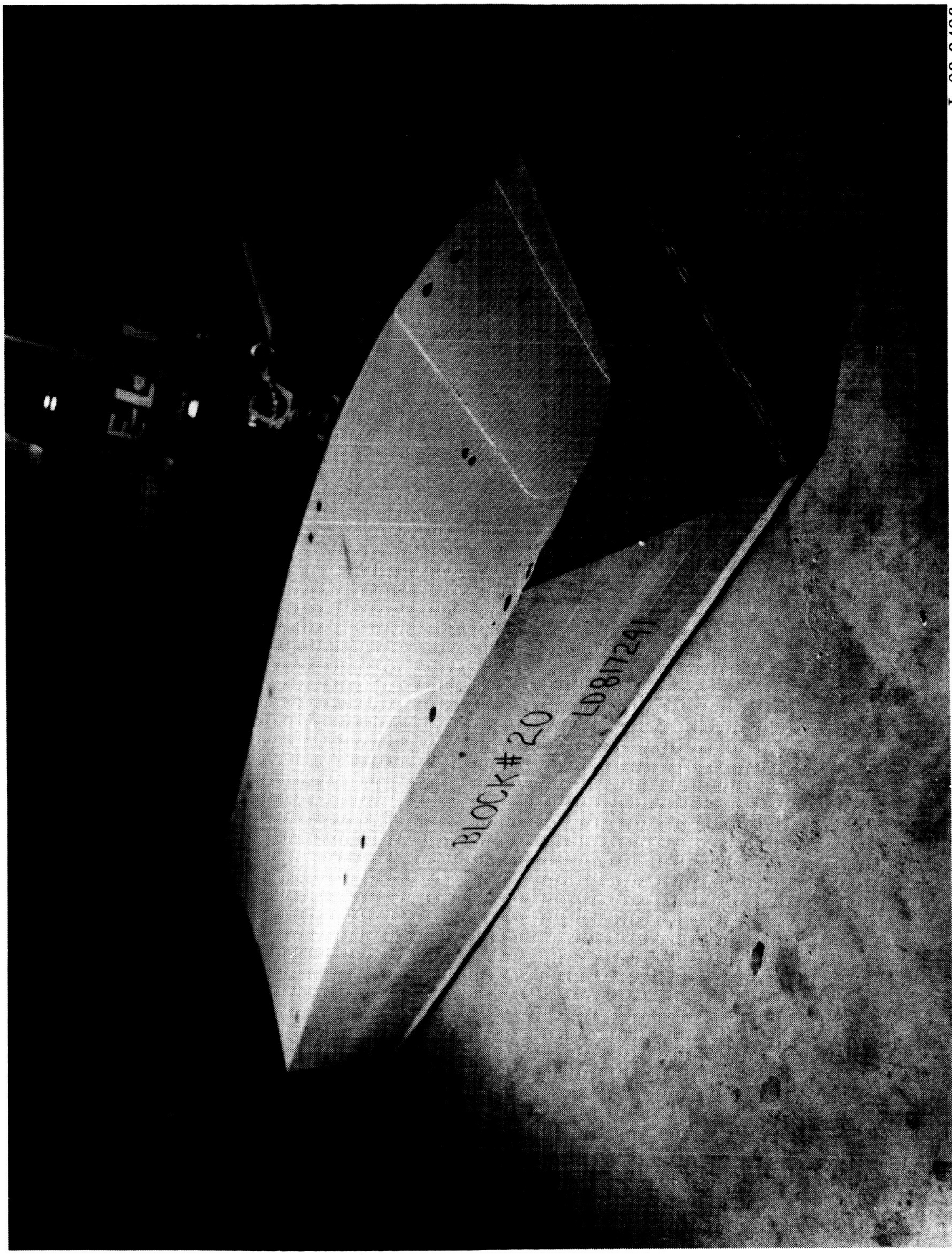
Figure 31. Continued.



L-81-9808

(k) View of back side of west wall choke plate showing mounting hardware and actuators.

Figure 31. Concluded.



L-80-9486

Figure 32. Foam liner blocks.

L-81-7614

Figure 32. Concluded.

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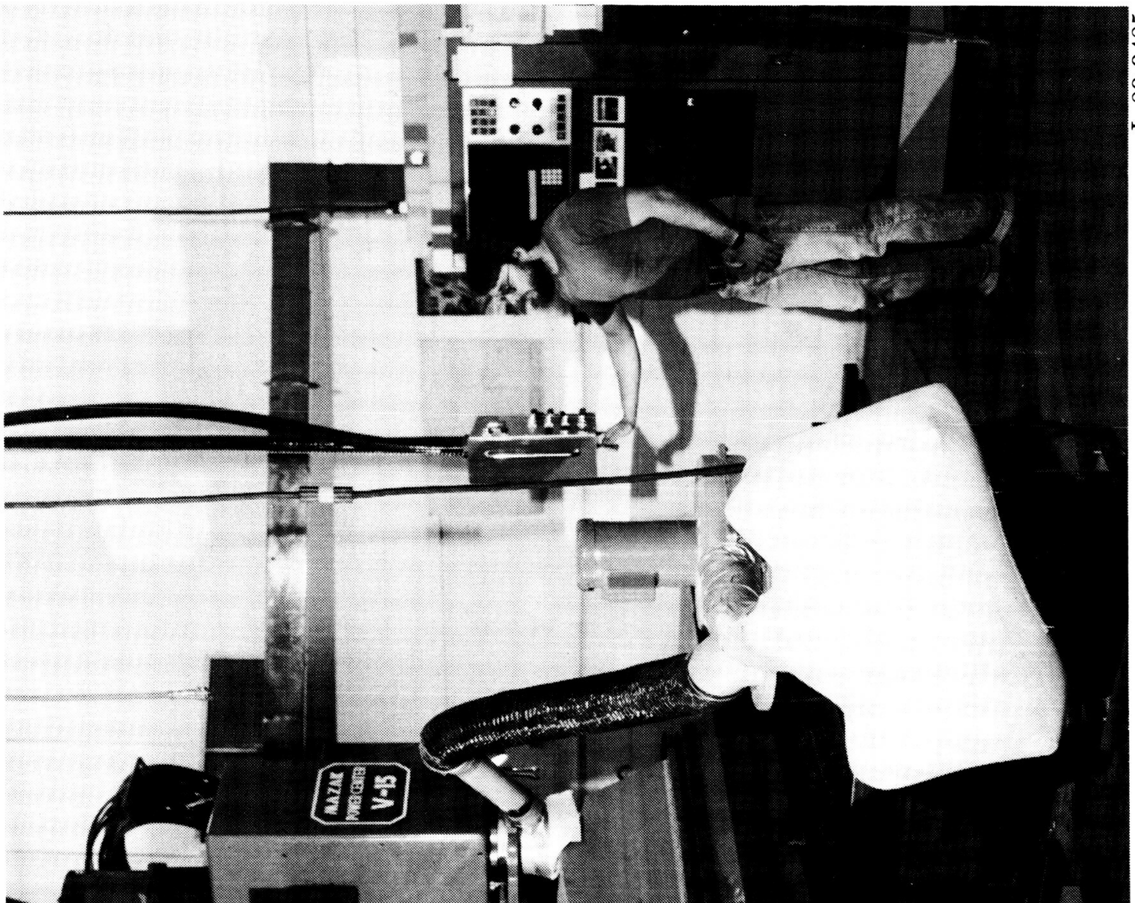


L-80-9485

Figure 33. Foam liner block during numerical milling process.

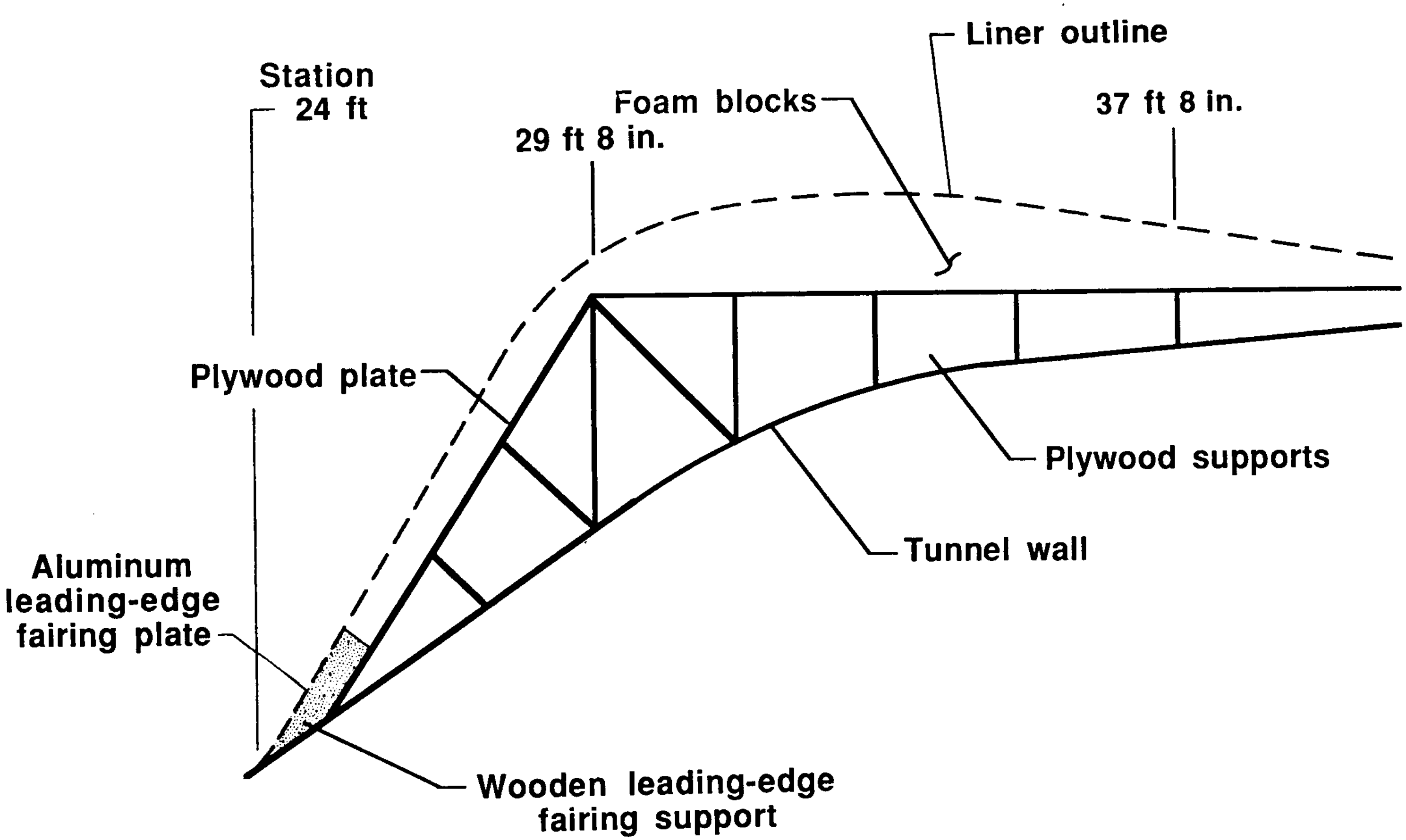
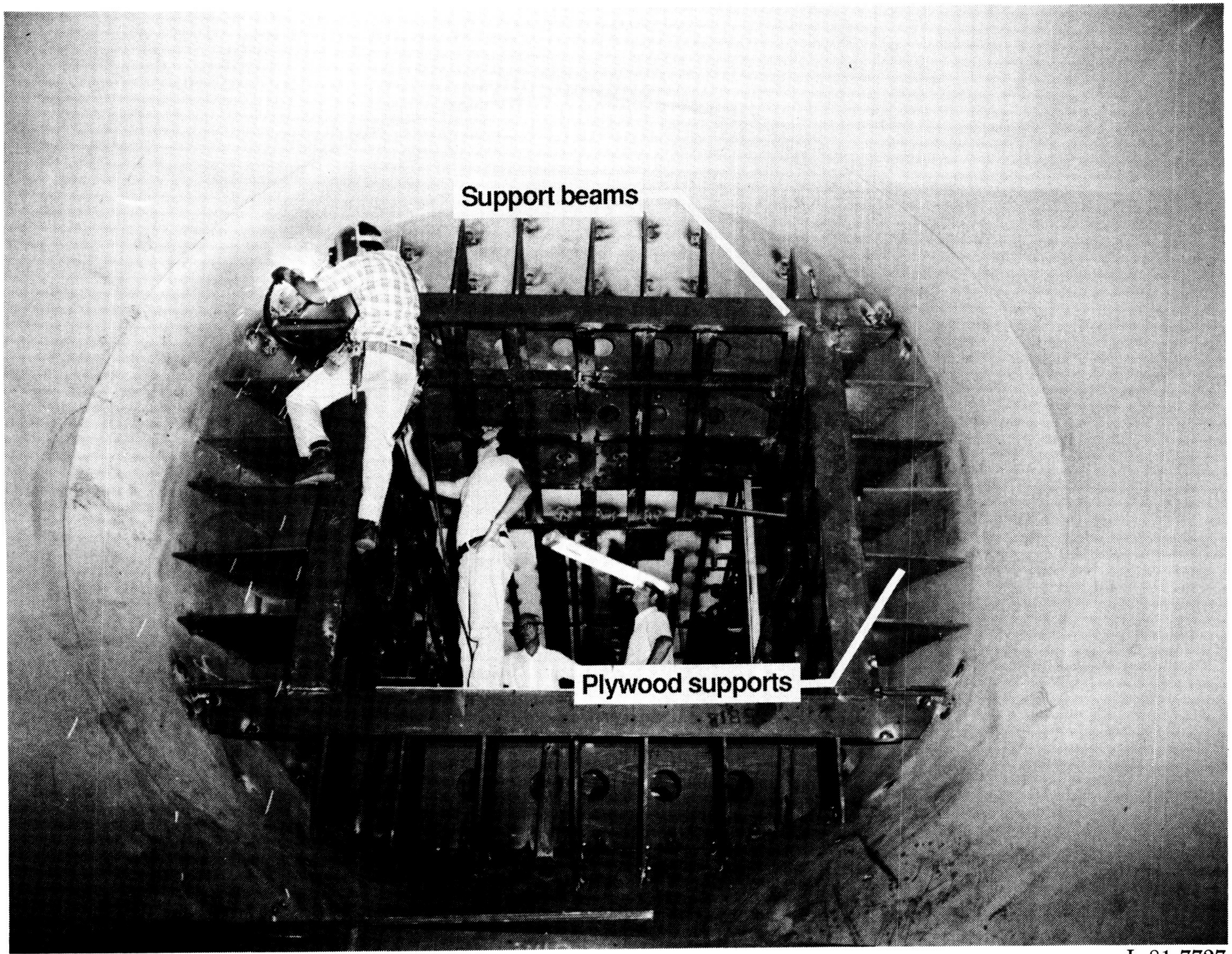


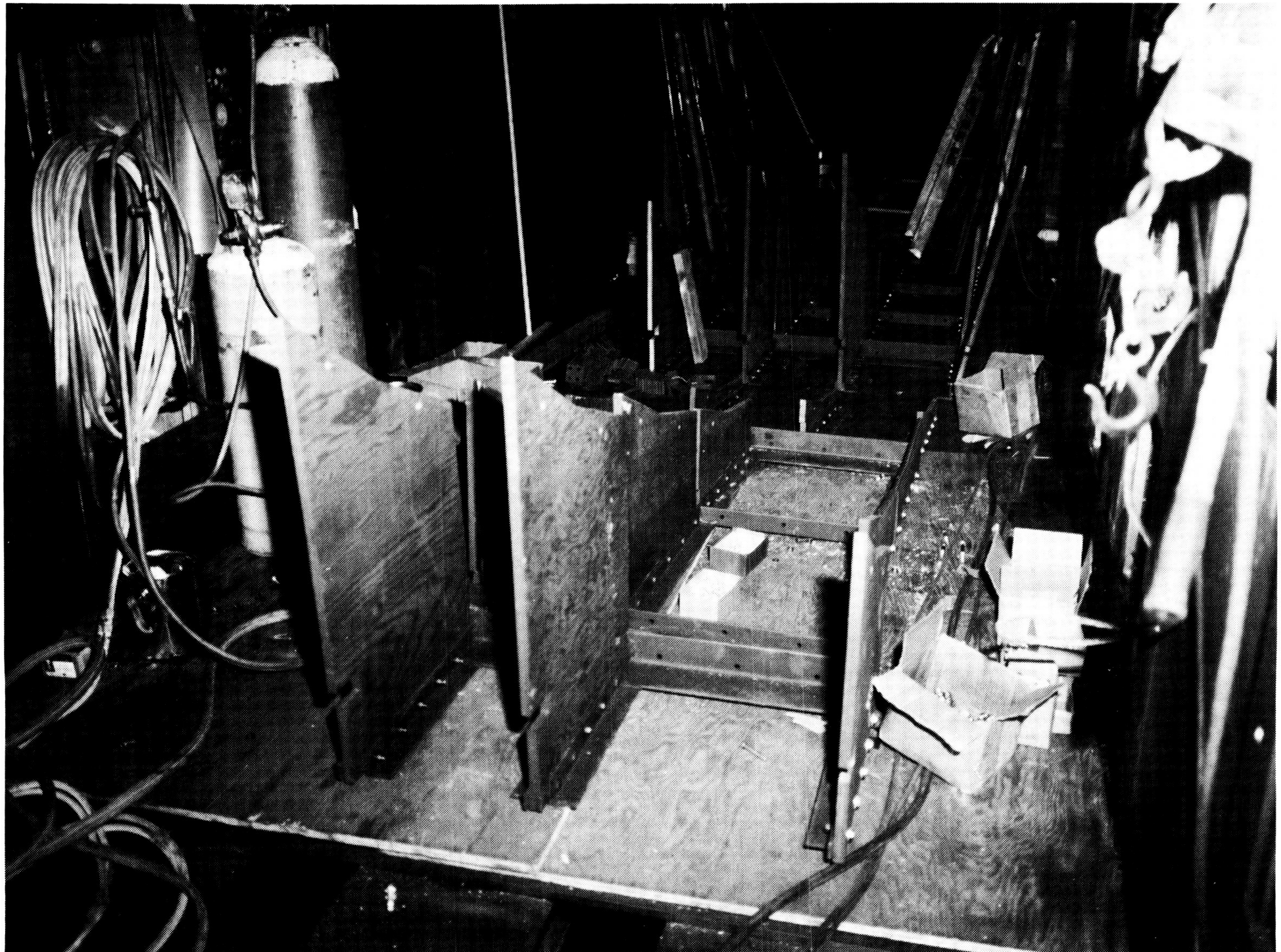
Figure 34. Sketch of liner substructure cross section in vicinity of entrance cone region.



L-81-7727

(a) Plywood supports nested behind support beams.

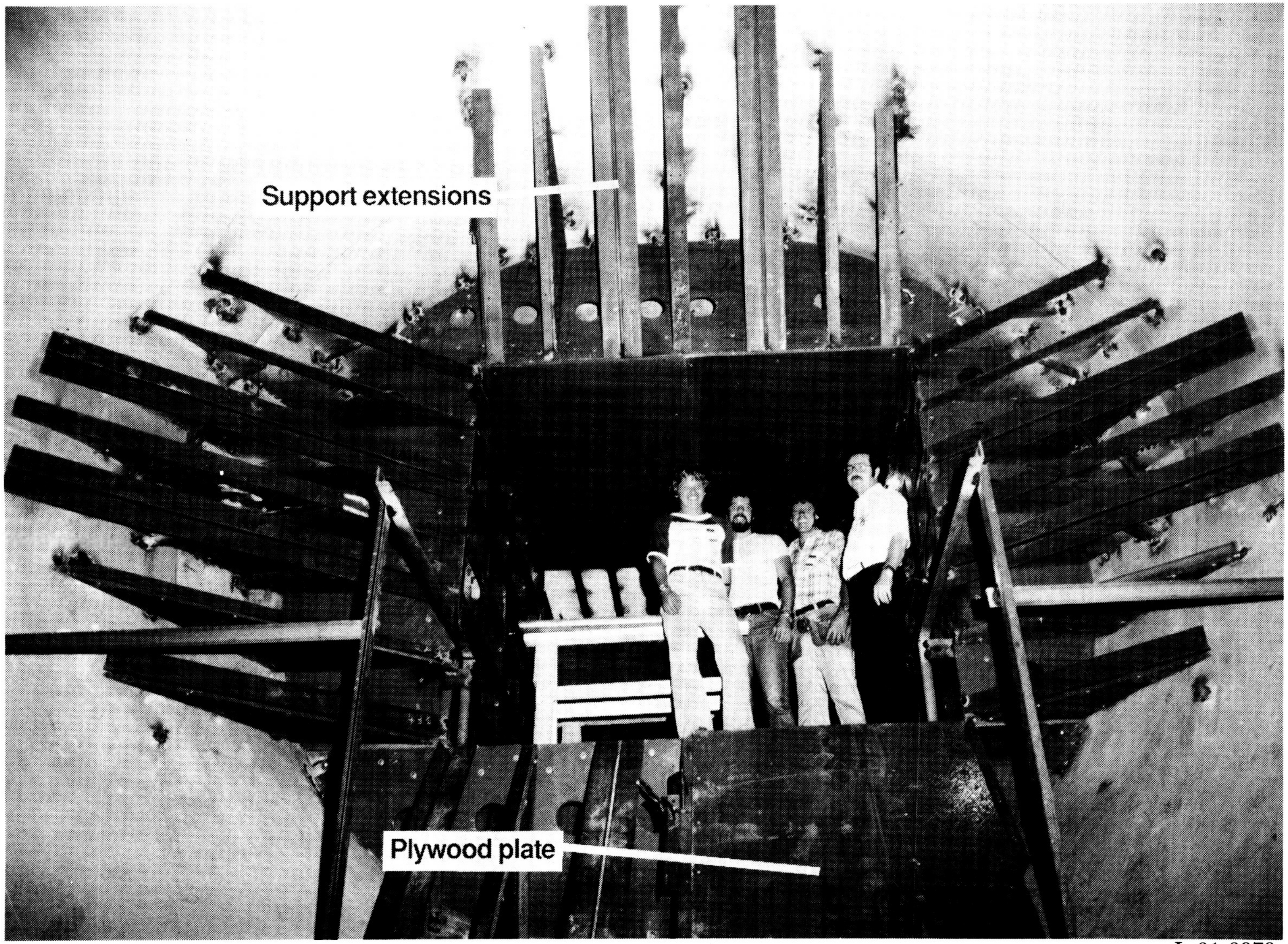
Figure 35. Liner substructure in vicinity of entrance cone region during various stages of installation.



L-81-7596

(b) Plywood supports in test section before installation.

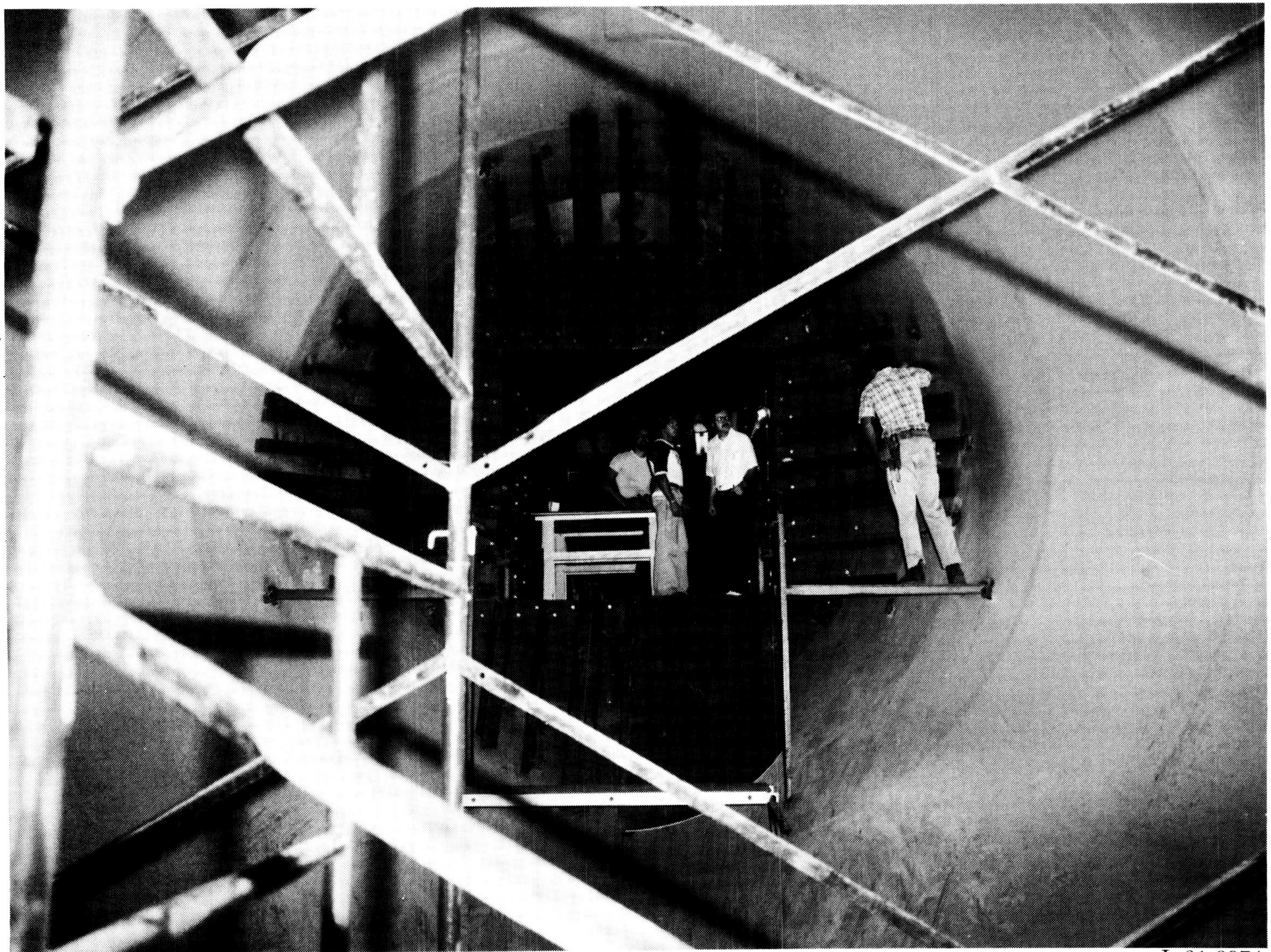
Figure 35. Continued.



L-81-8070

(c) Support extensions.

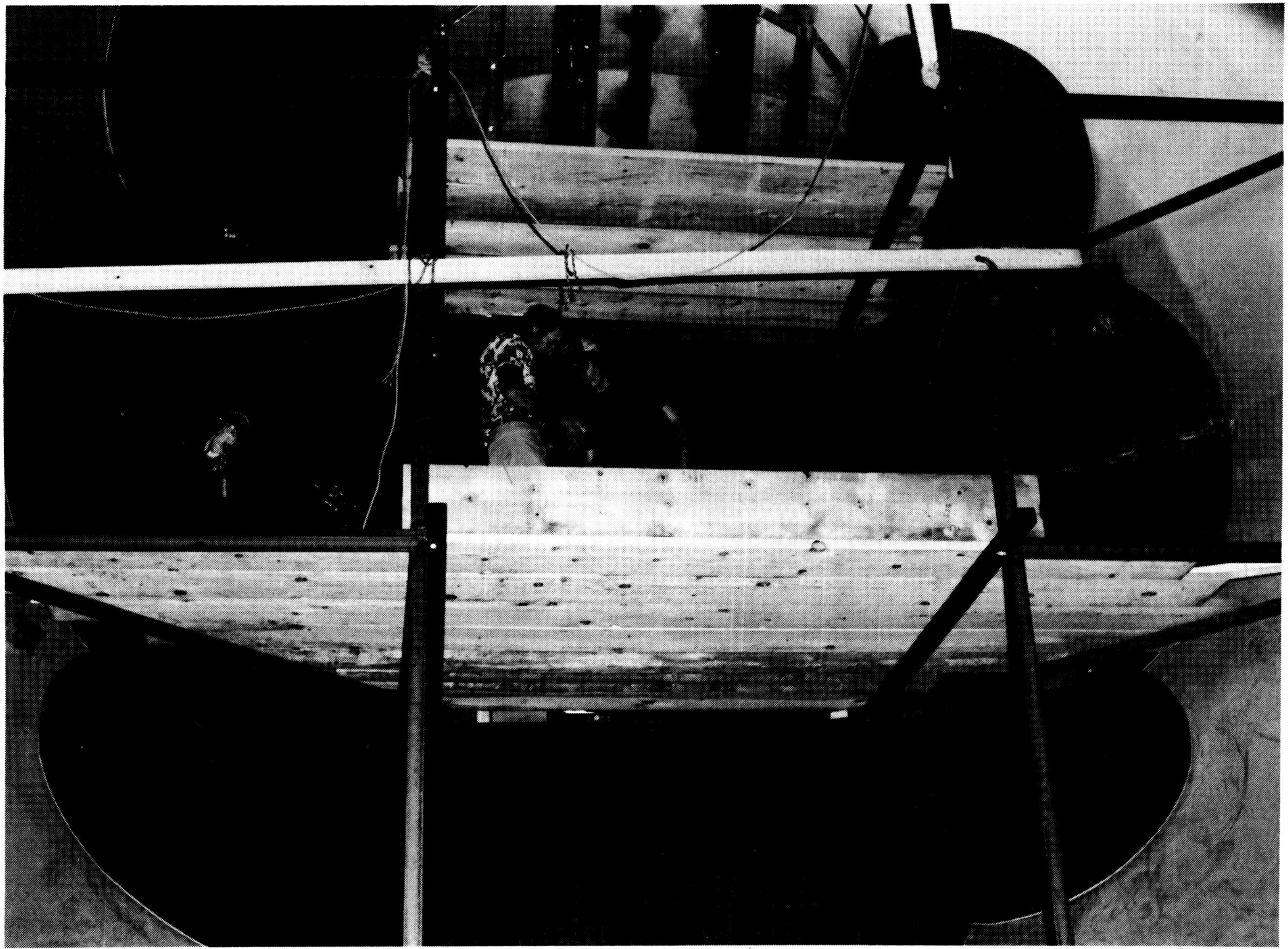
Figure 35. Continued.



L-81-8074

(d) Support extensions and plywood plates.

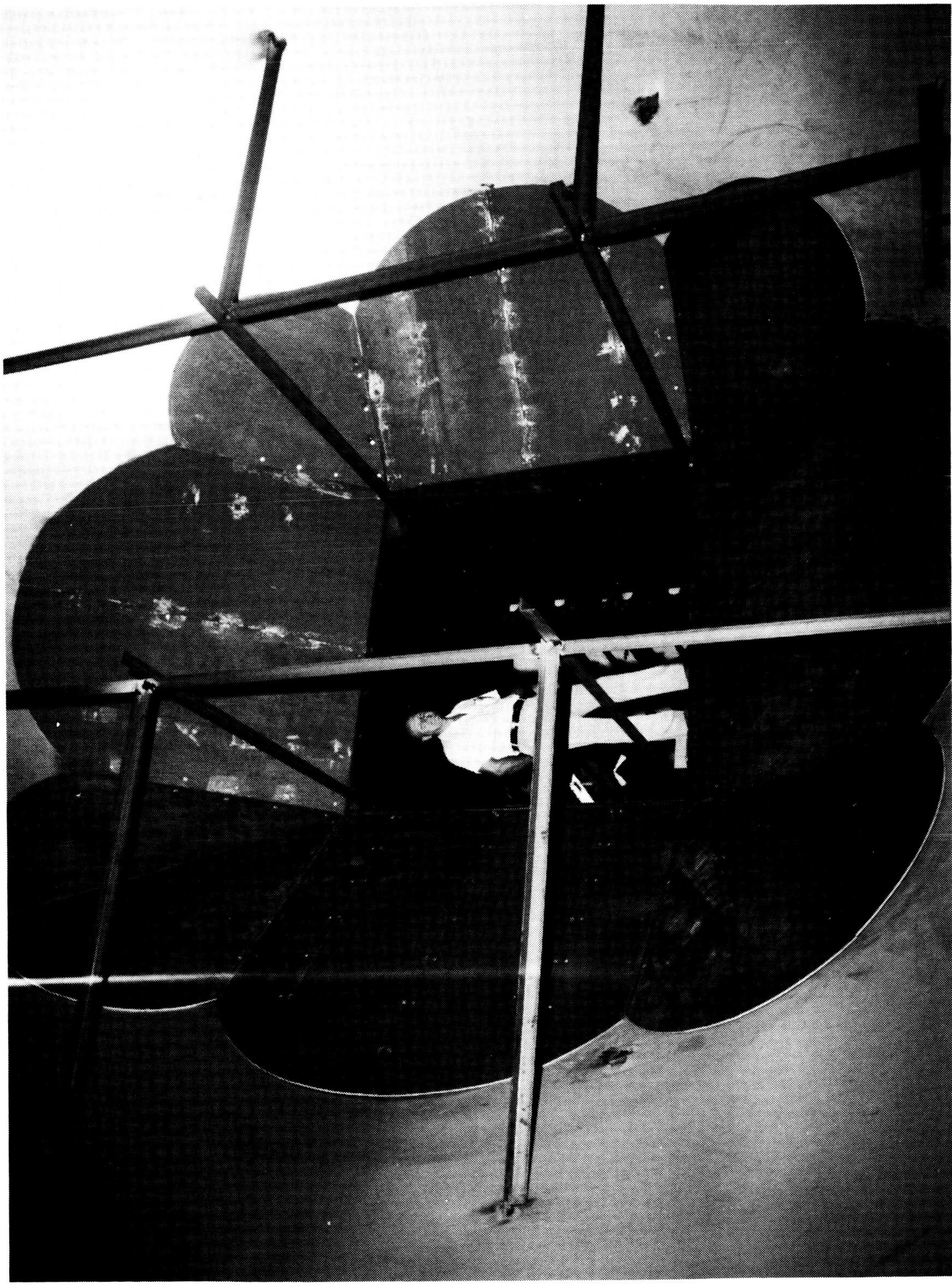
Figure 35. Continued.



L-81-9126

(e) Plywood plates.

Figure 35. Continued.



L-81-8496

(e) Concluded.

Figure 35. Concluded.

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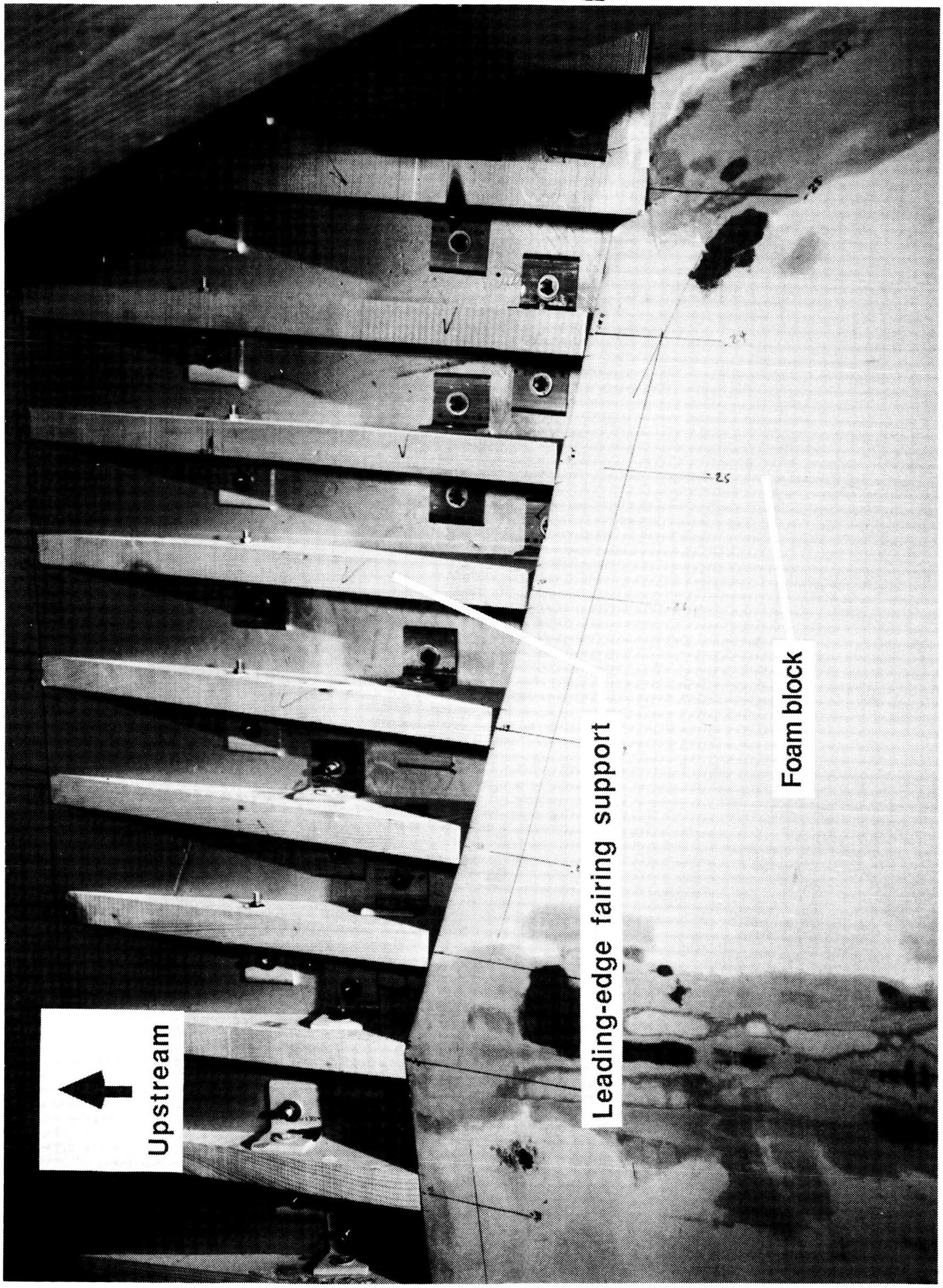
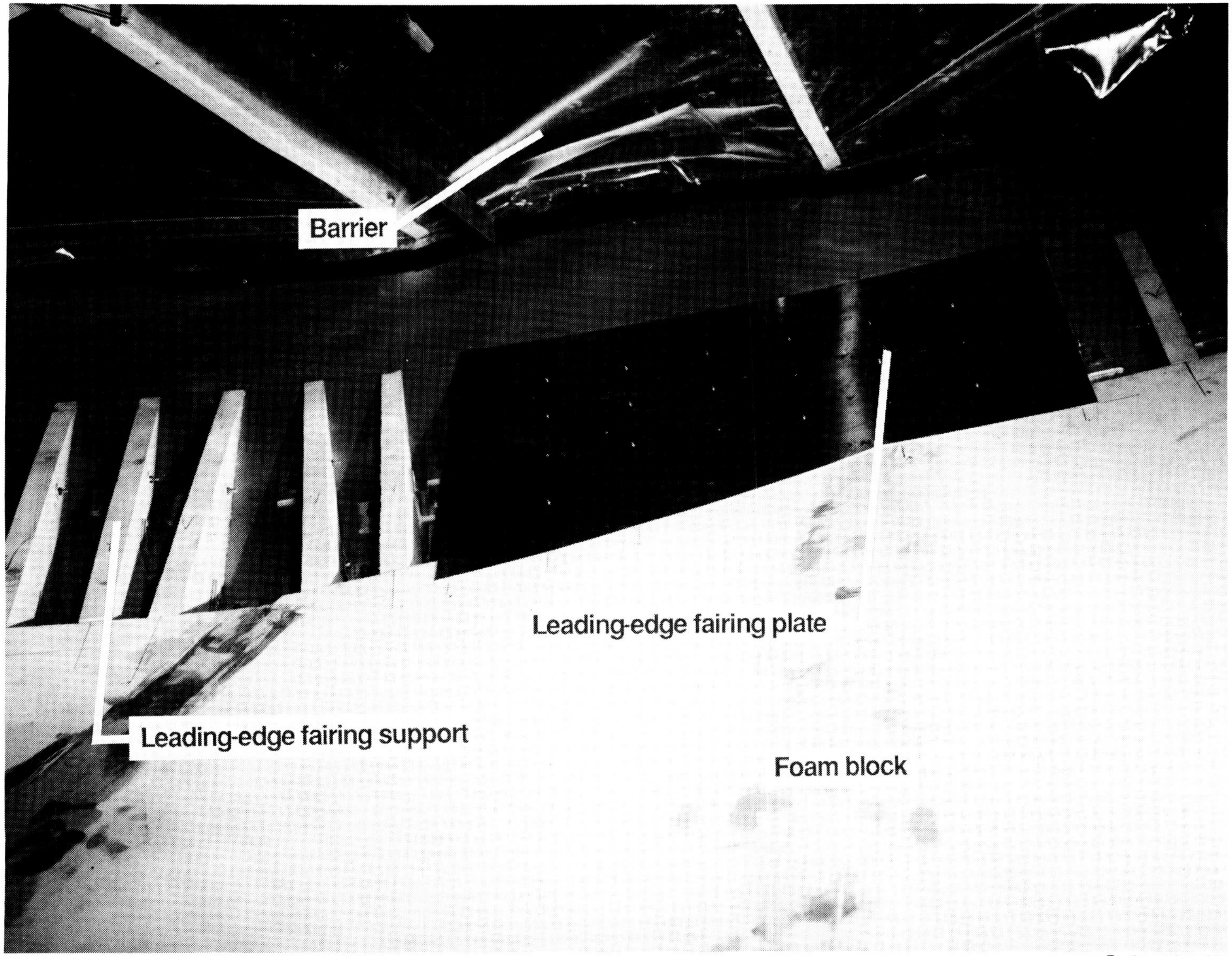


(a) Leading-edge fairing supports.

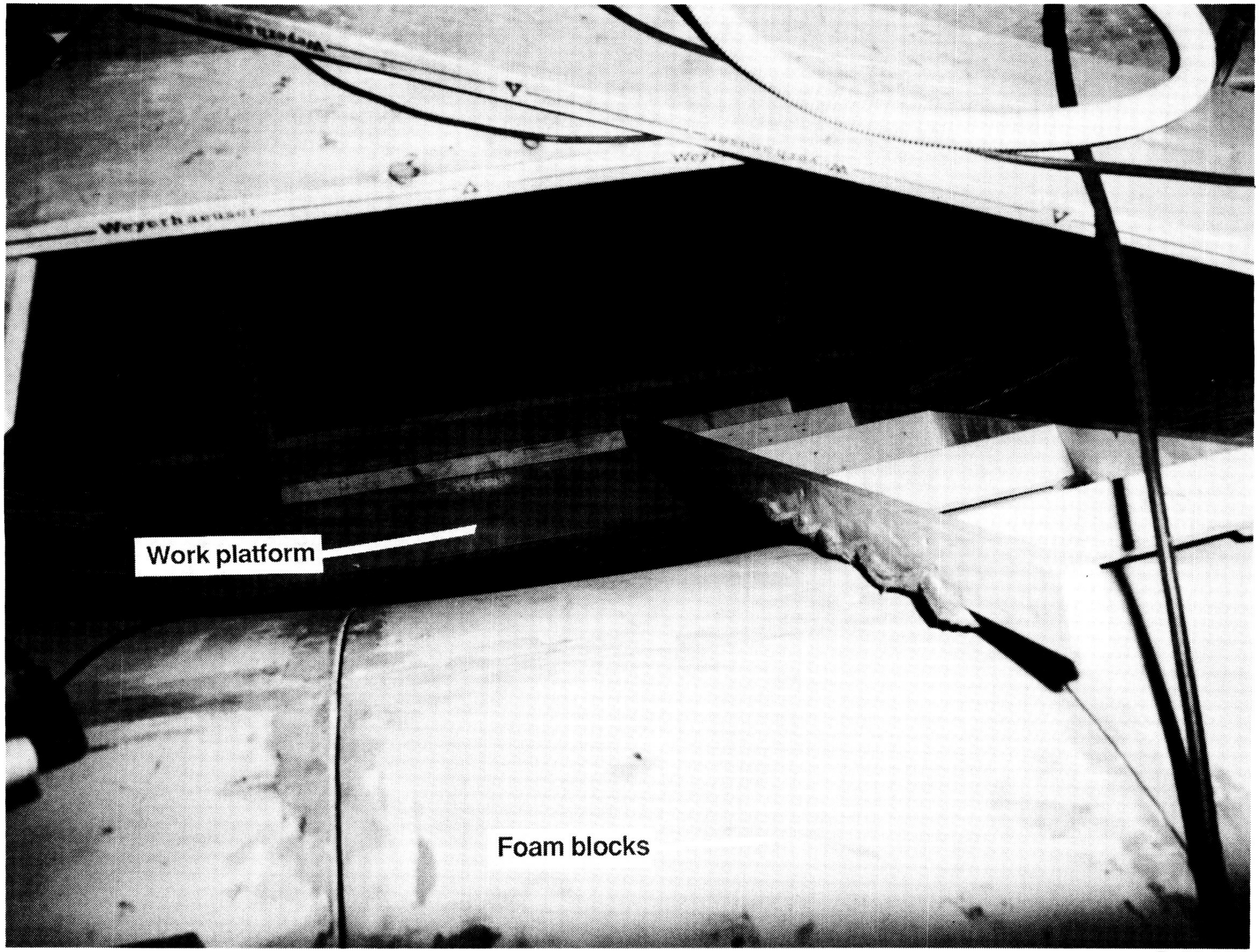
Figure 36. Liner leading-edge fairing supports and plates.



L-81-10,145

(b) Leading-edge fairing plate.

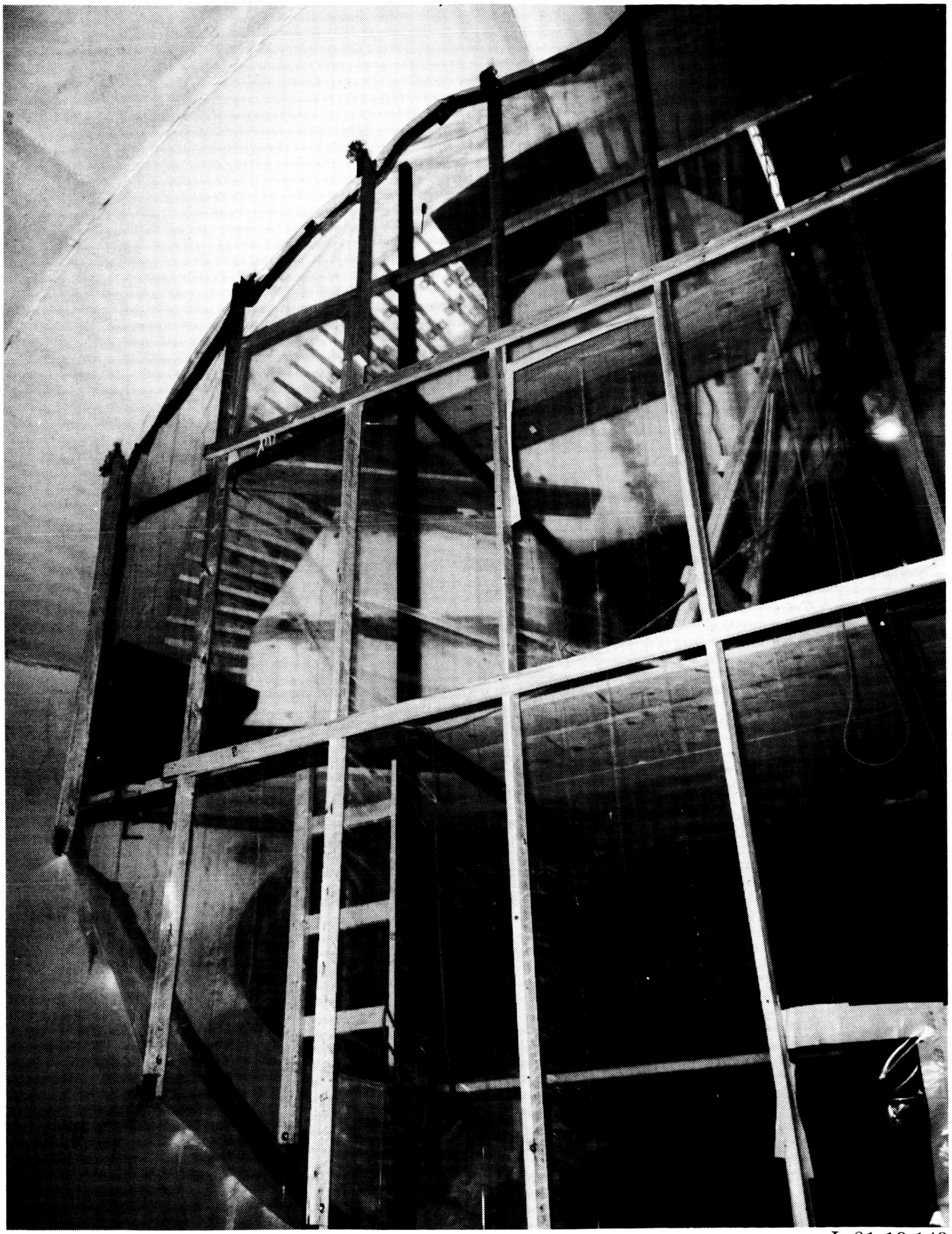
Figure 36. Concluded.



L-82-524

(a) Work platform.

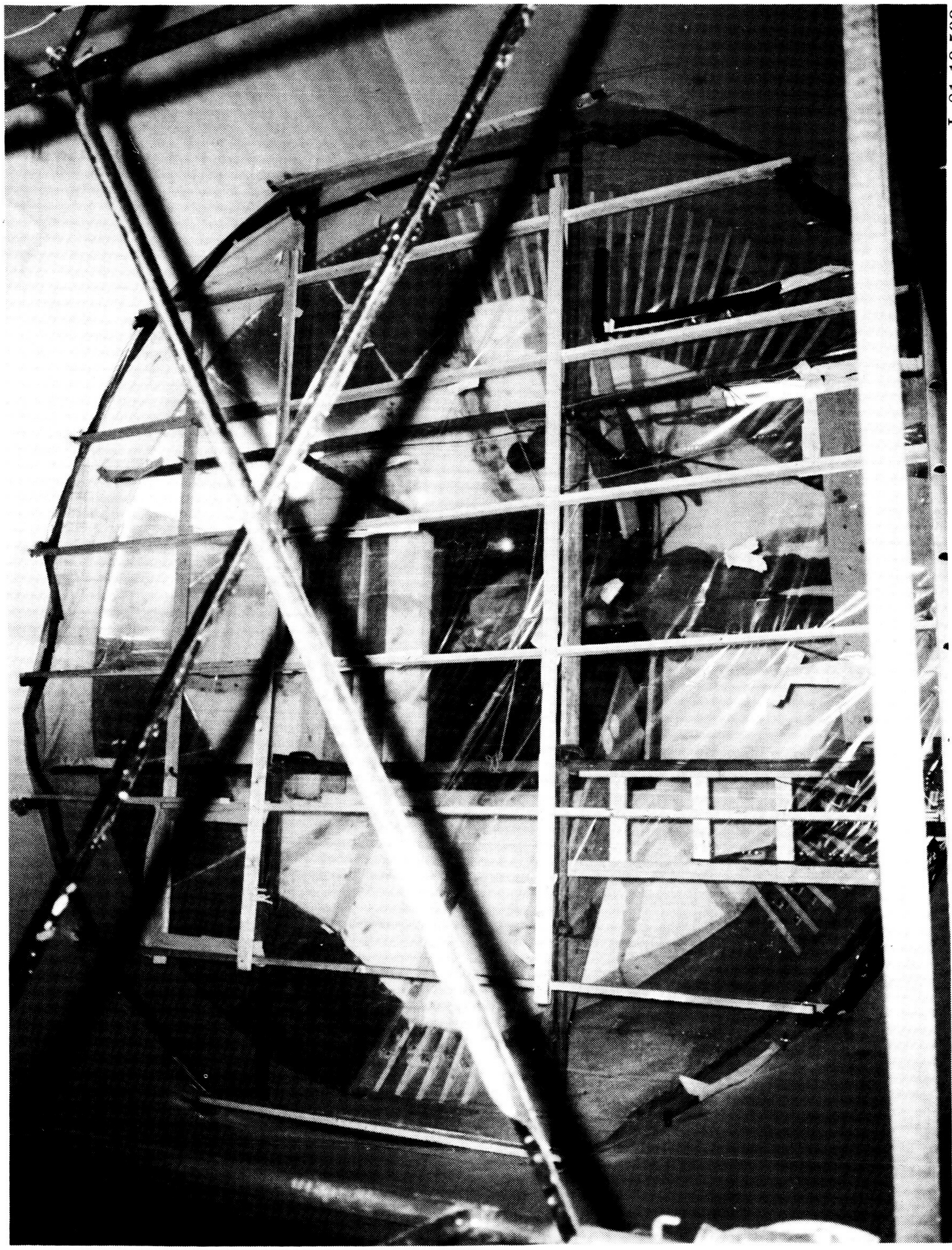
Figure 37. Liner leading-edge fairing during various stages of installation.



L-81-10,149

(b) Leading-edge fairings and scaffolding.

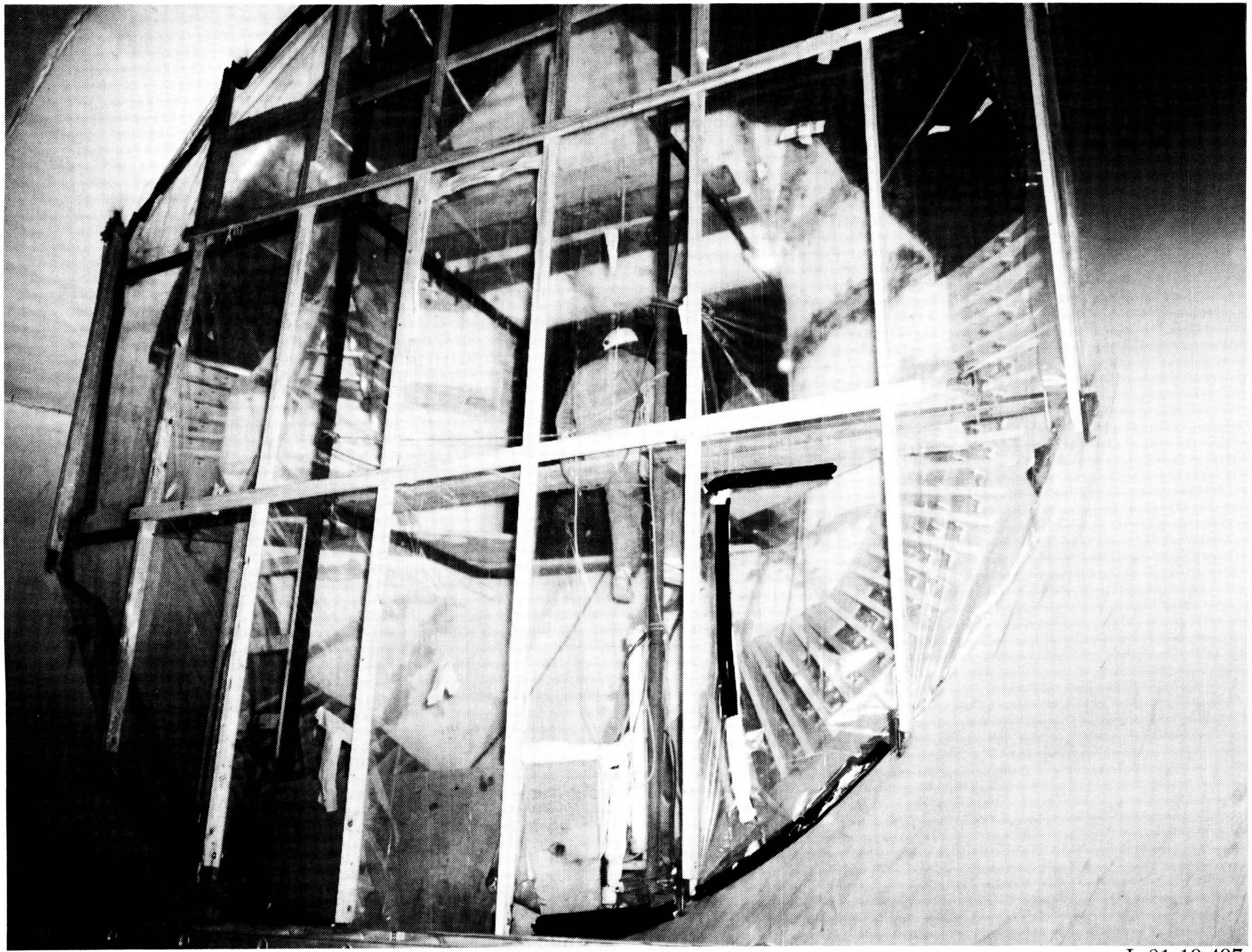
Figure 37. Continued.



L-81-10,500

(b) Continued.

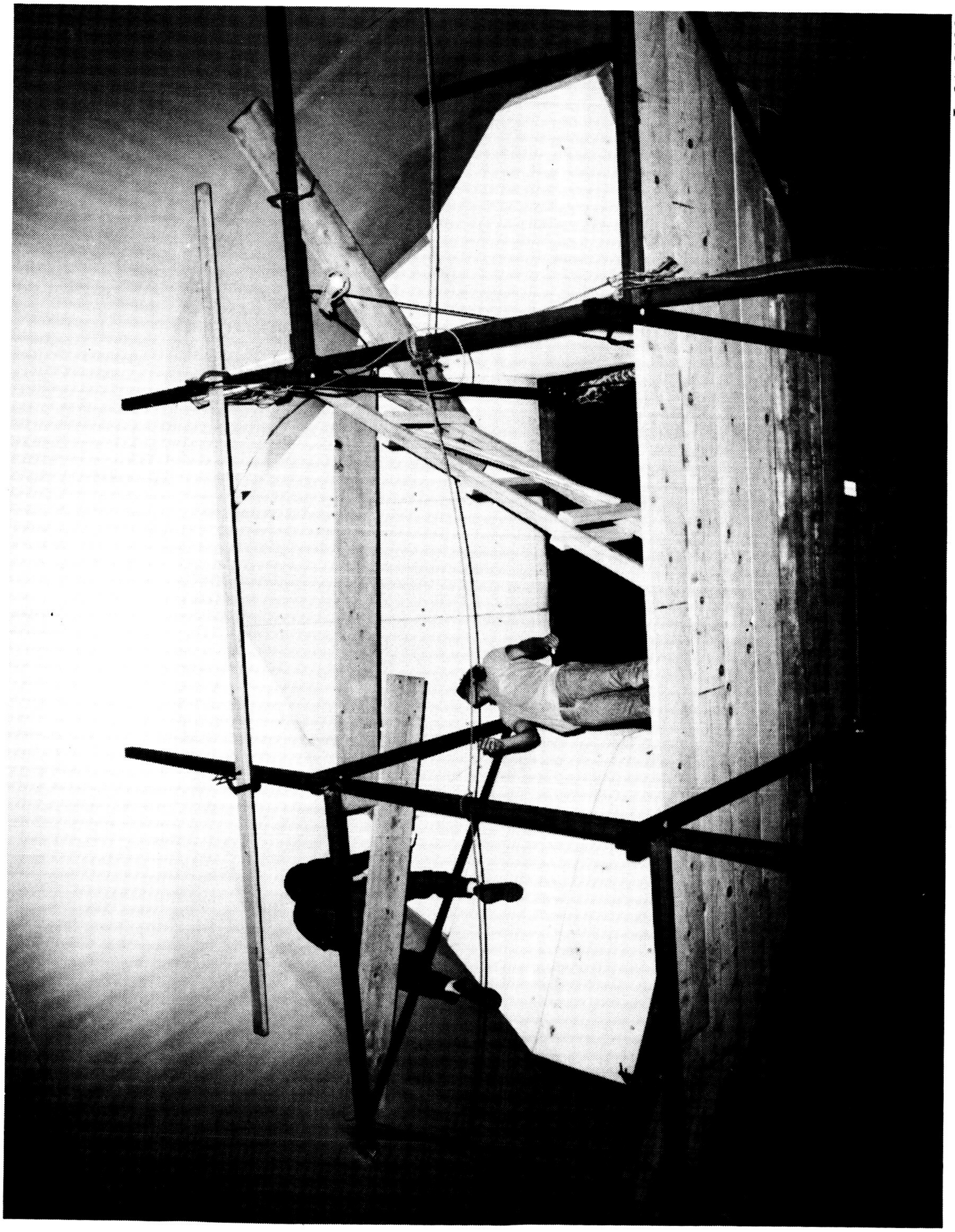
Figure 37. Continued.



L-81-10,497

(b) Continued.

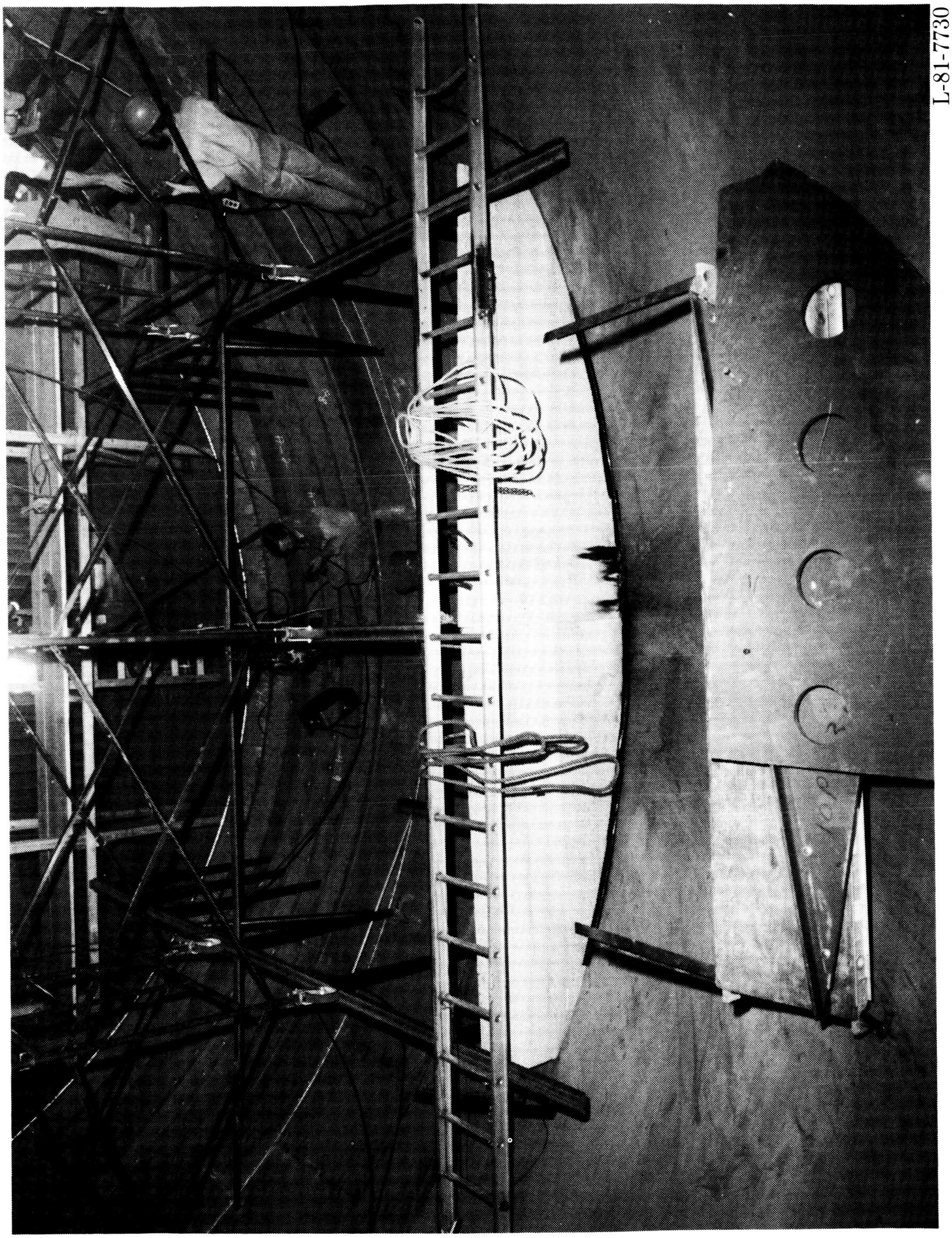
Figure 37. Continued.



L-81-9489

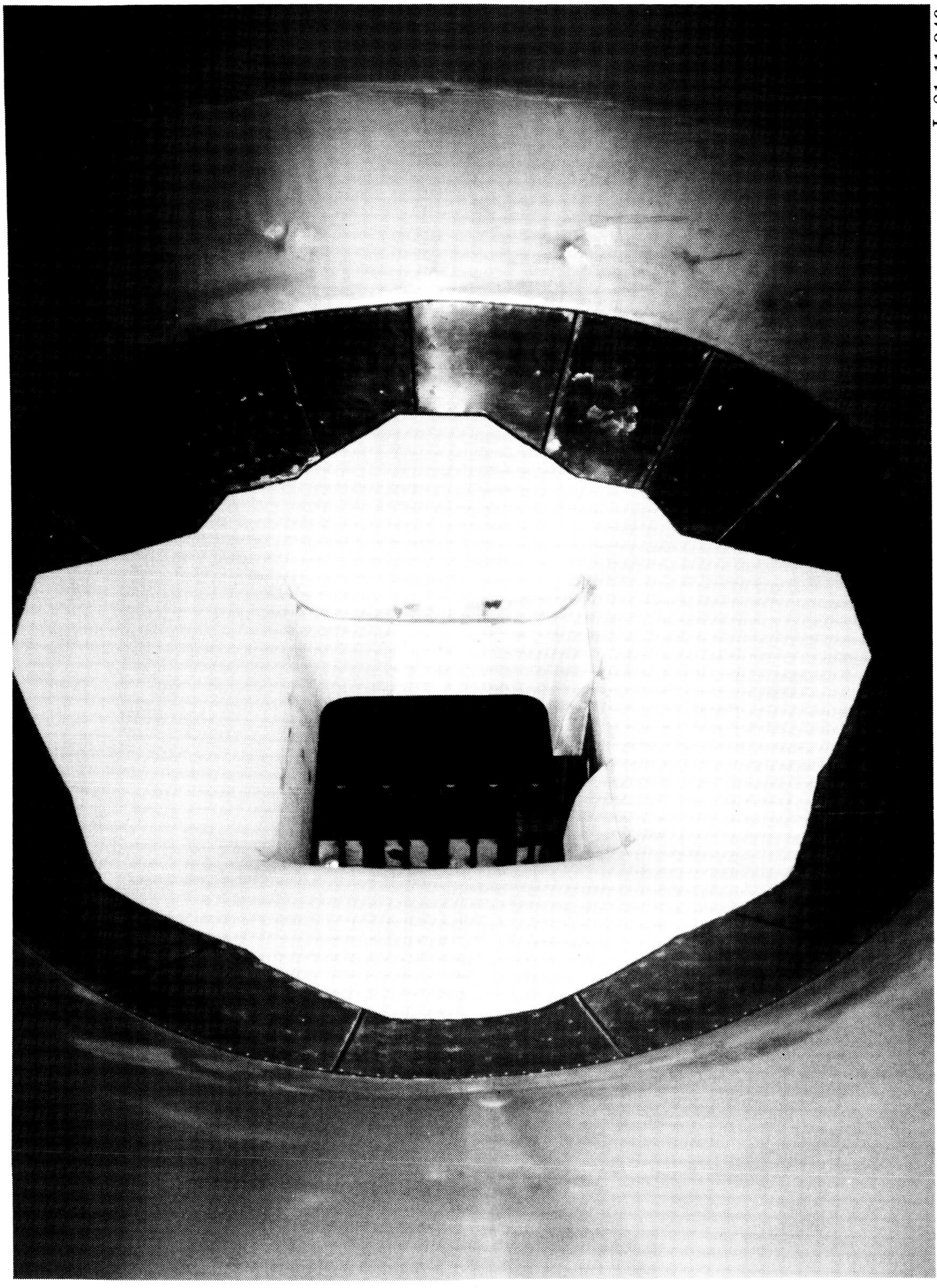
(b) Concluded.

Figure 37. Concluded.



L-81-7730

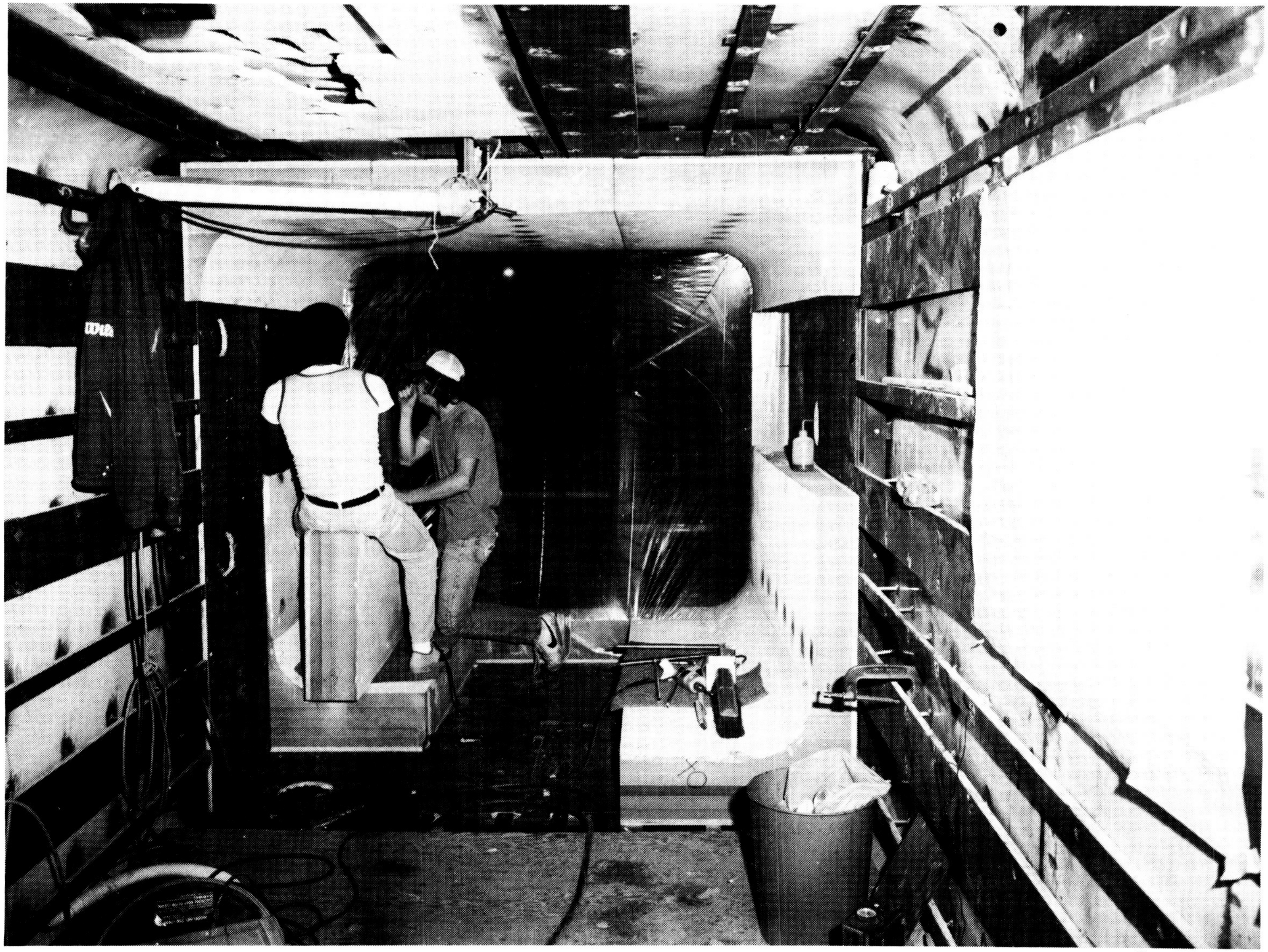
Figure 38. Protective barrier on floor of tunnel between liner and screens.



L-81-11,046

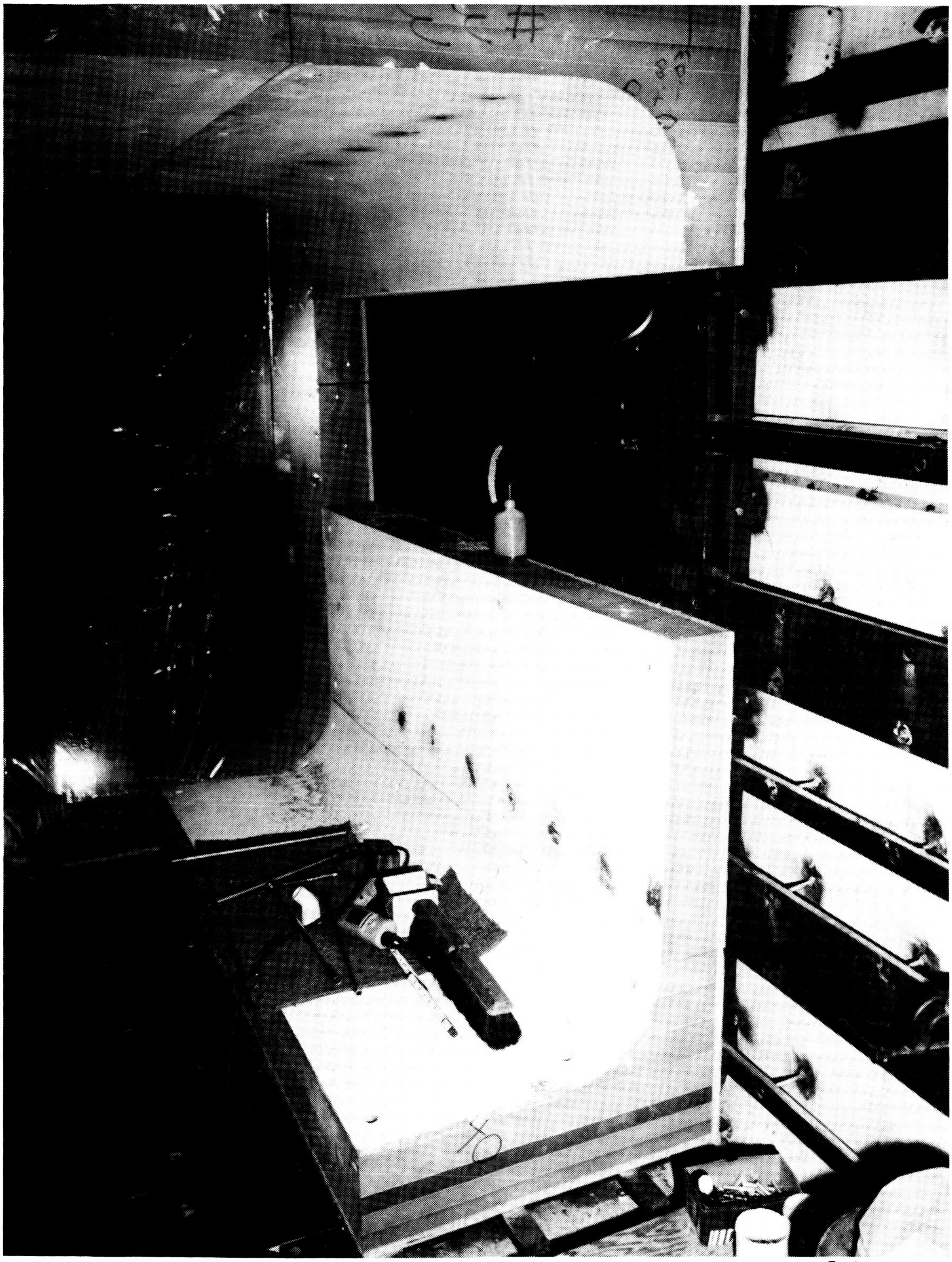
Figure 39. Completed entrance cone with one foam block on floor of test section removed.

C-3



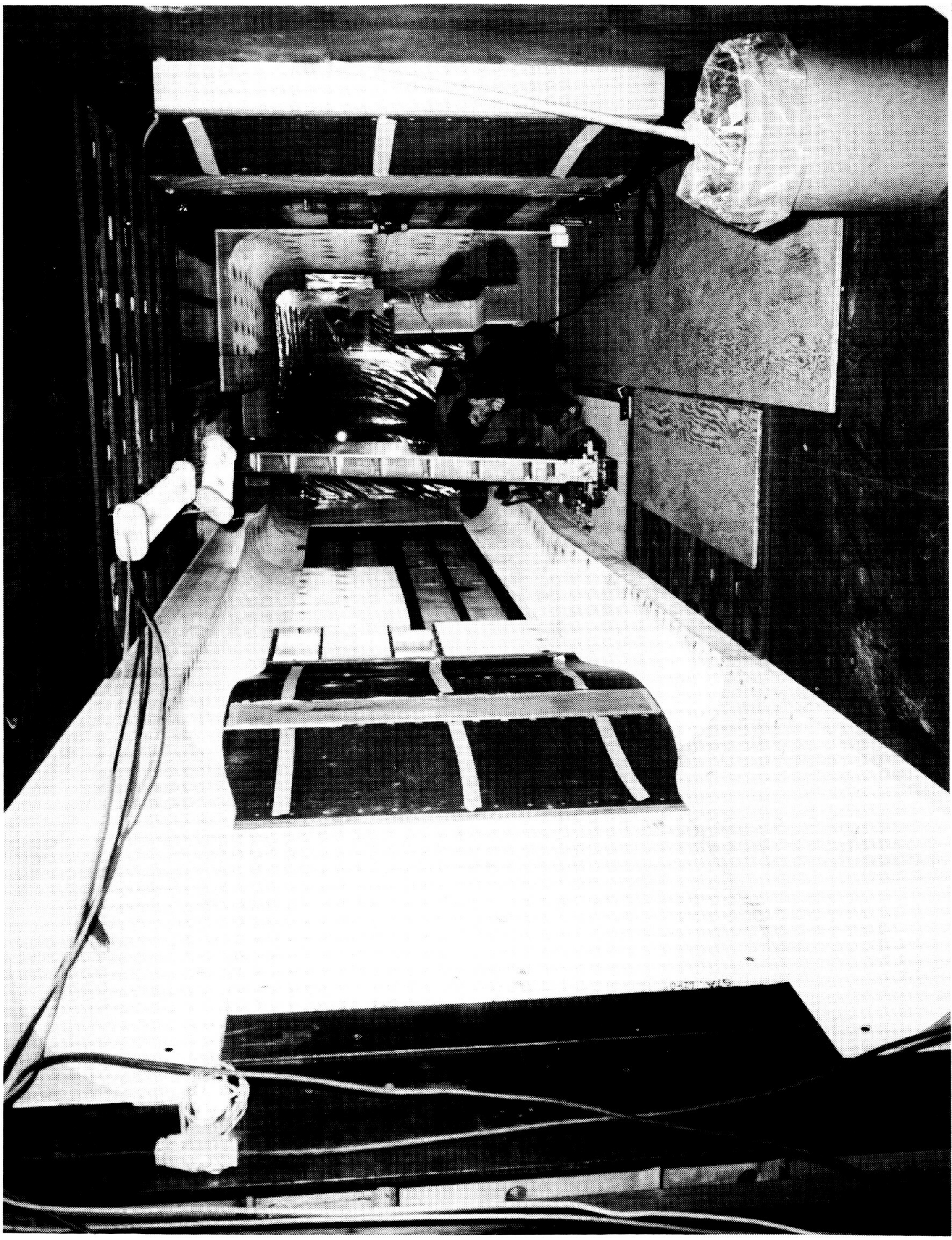
L-81-11,052

Figure 40. Various stages of installation of foam blocks through the test section.



L-81-11,057

Figure 40. Continued.



L-81-11,607

Figure 40. Continued.

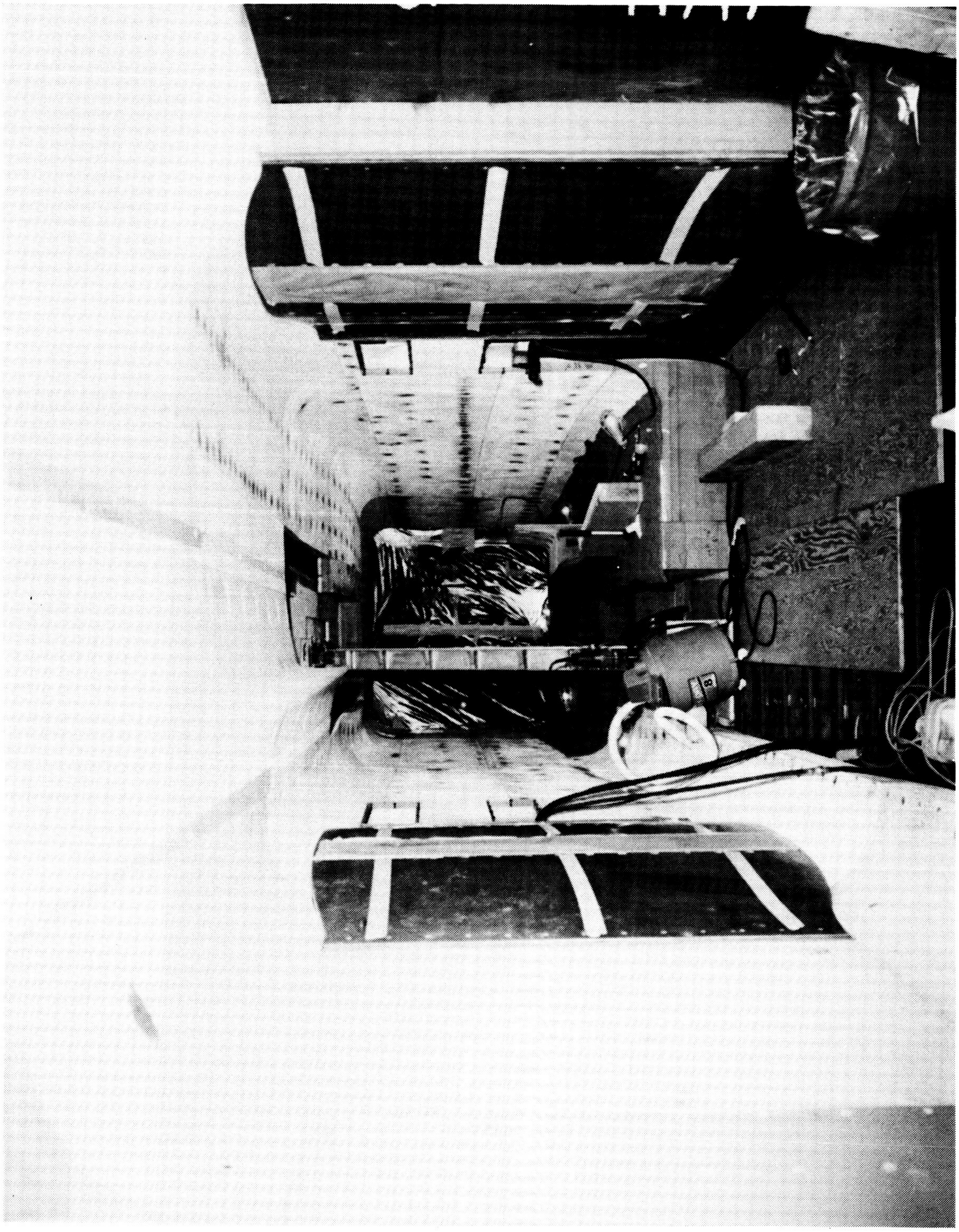
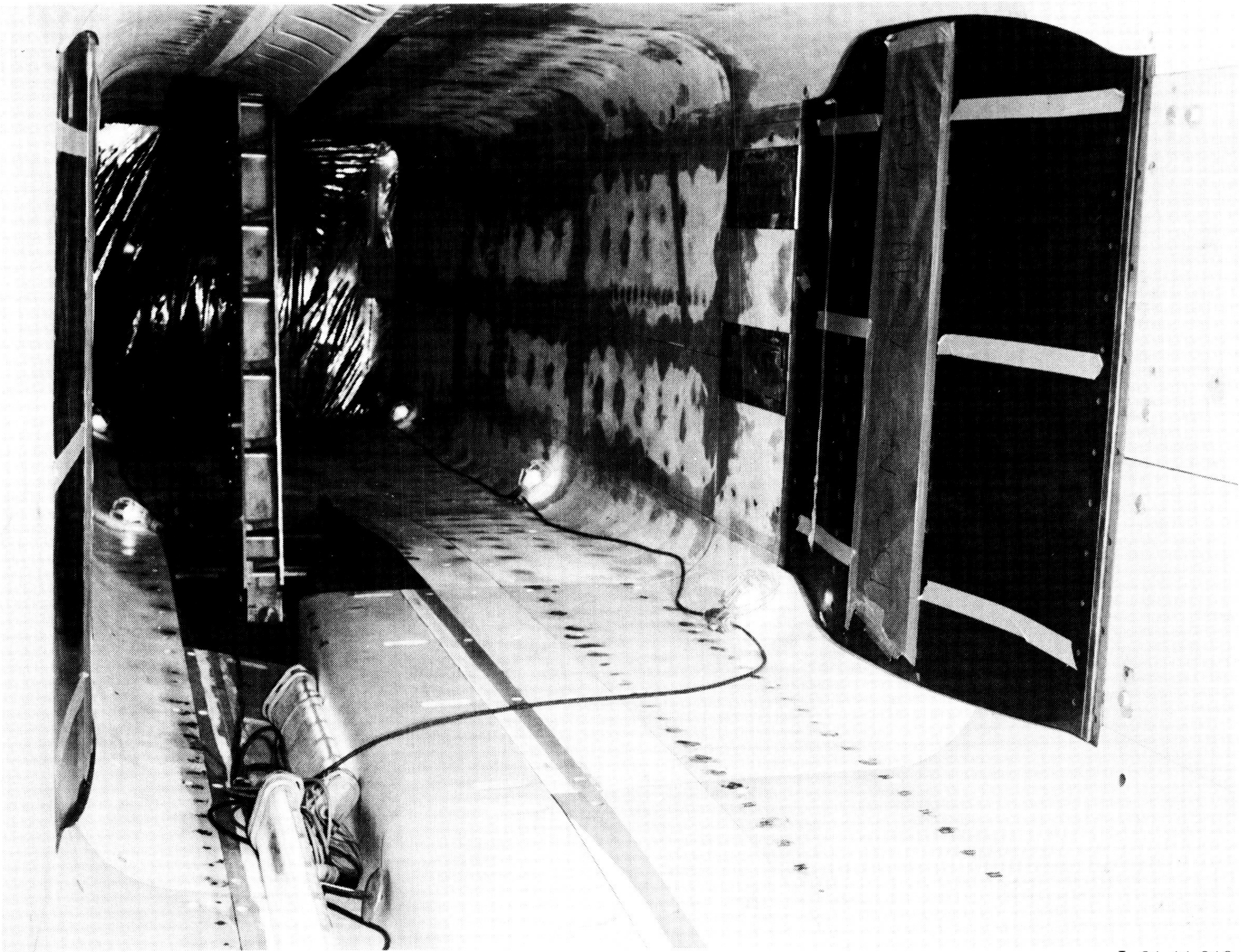
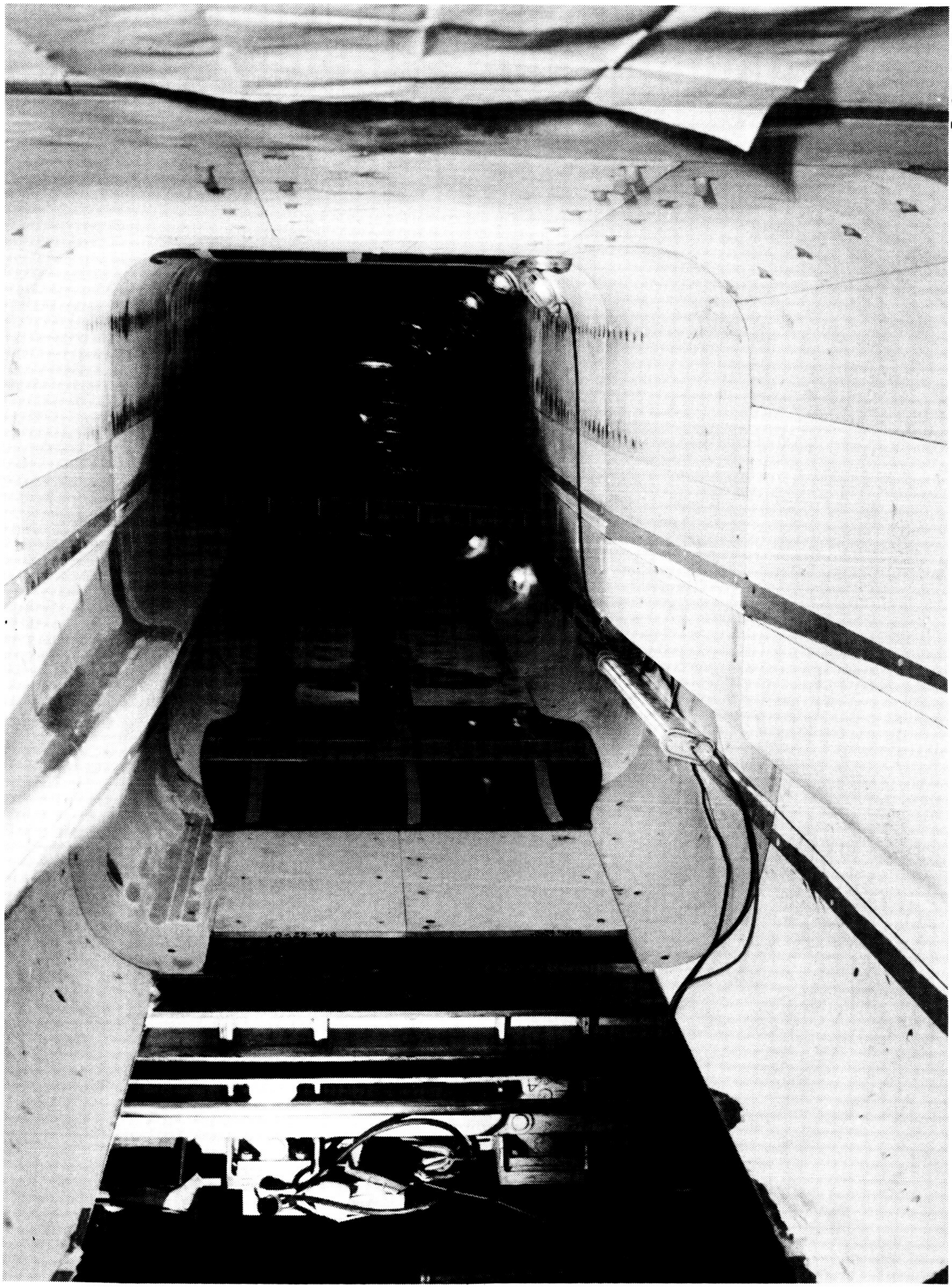

L-81-11,717

Figure 40. Continued.



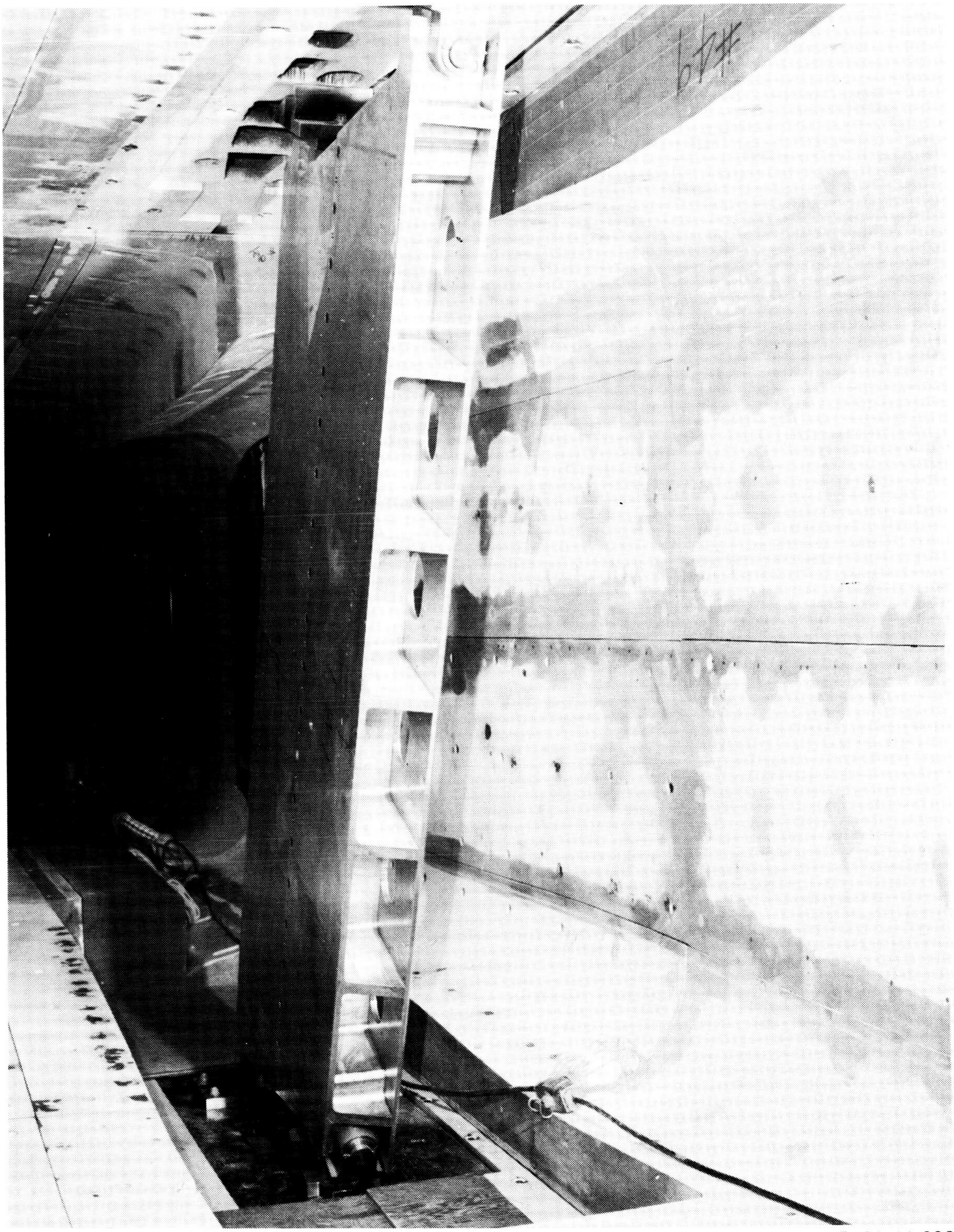
L-81-11,919

Figure 40. Continued.



L-81-11,918

Figure 40. Continued.

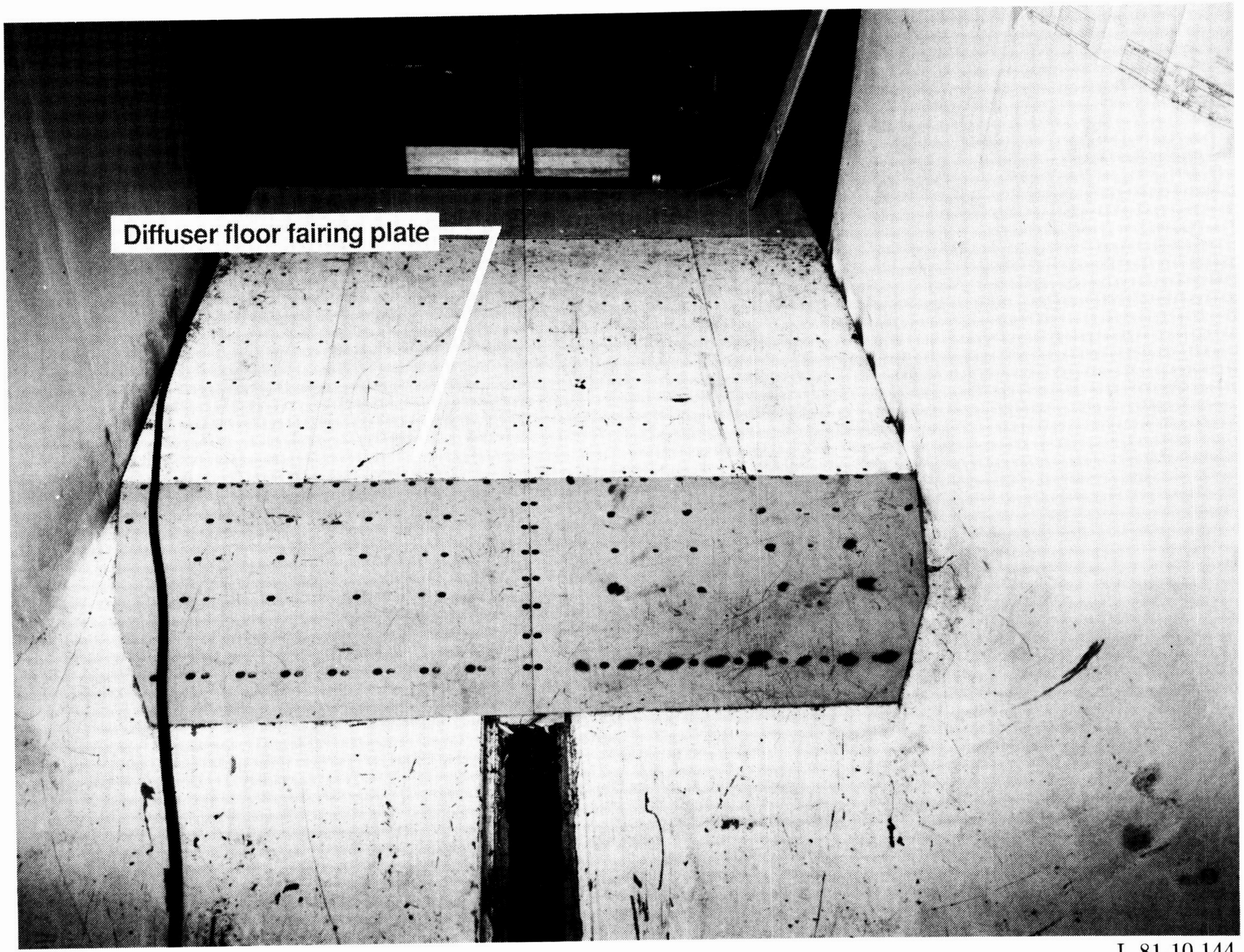


L-81-11,920

Figure 40. Concluded.

L-82-649

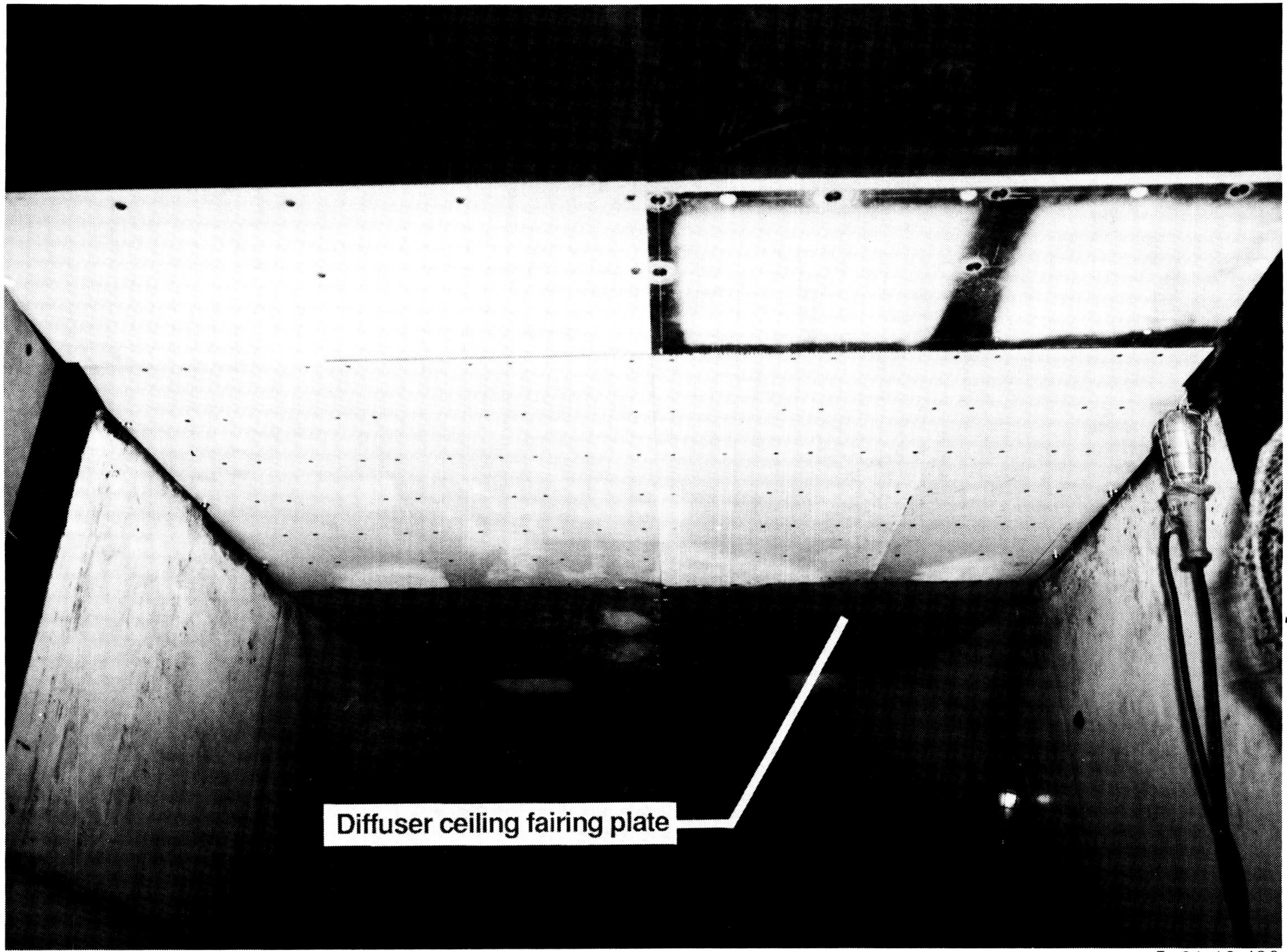
Figure 41. Foam block joint routing process.



L-81-10,144

(a) View upstream from diffuser of floor fairing plate.

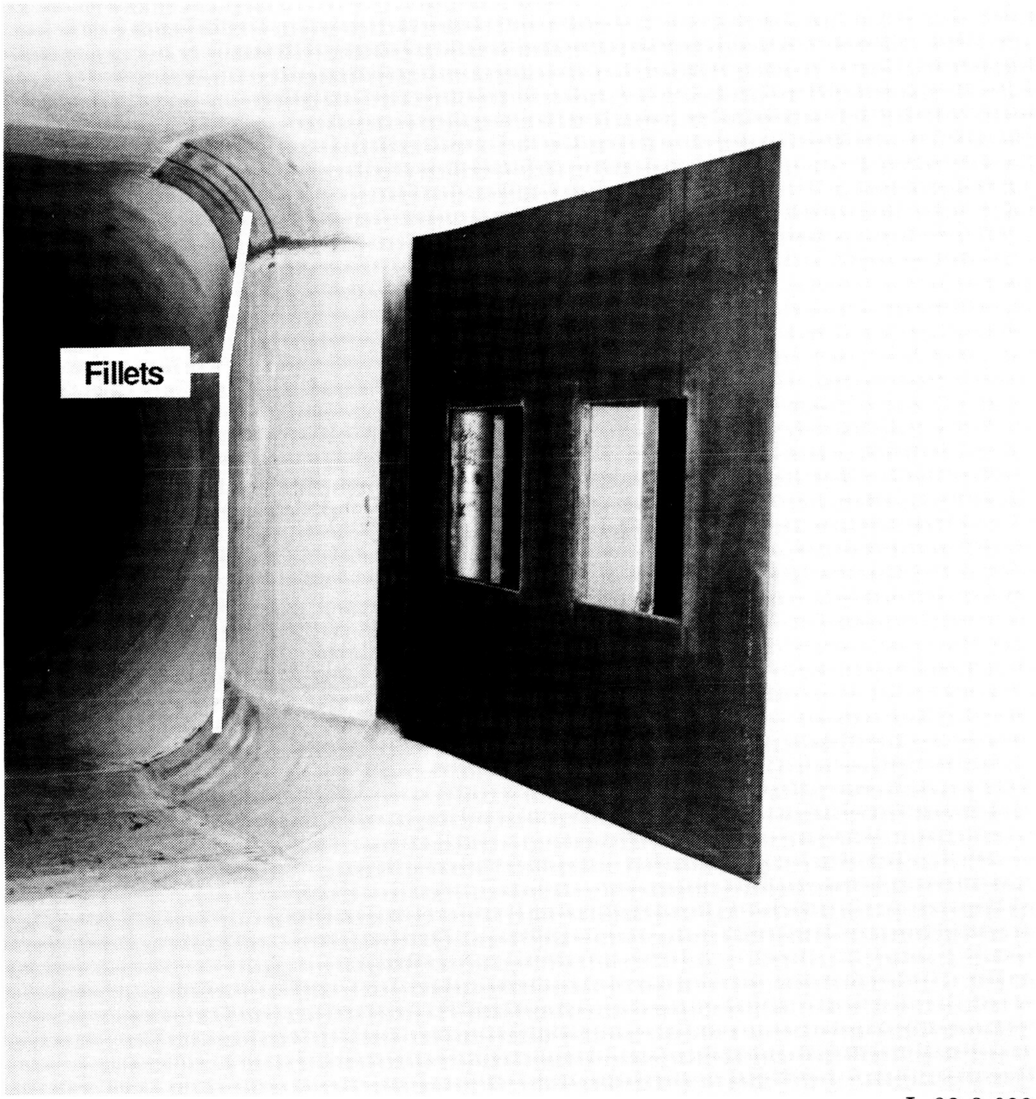
Figure 42. Liner fairing plates immediately downstream of test section access door.



L-81-10,496

(b) View downstream from test section of ceiling fairing plate.

Figure 42. Continued.



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(c) View downstream from test section of inside surface of access door and corner fillets downstream of door.

Figure 42. Concluded.

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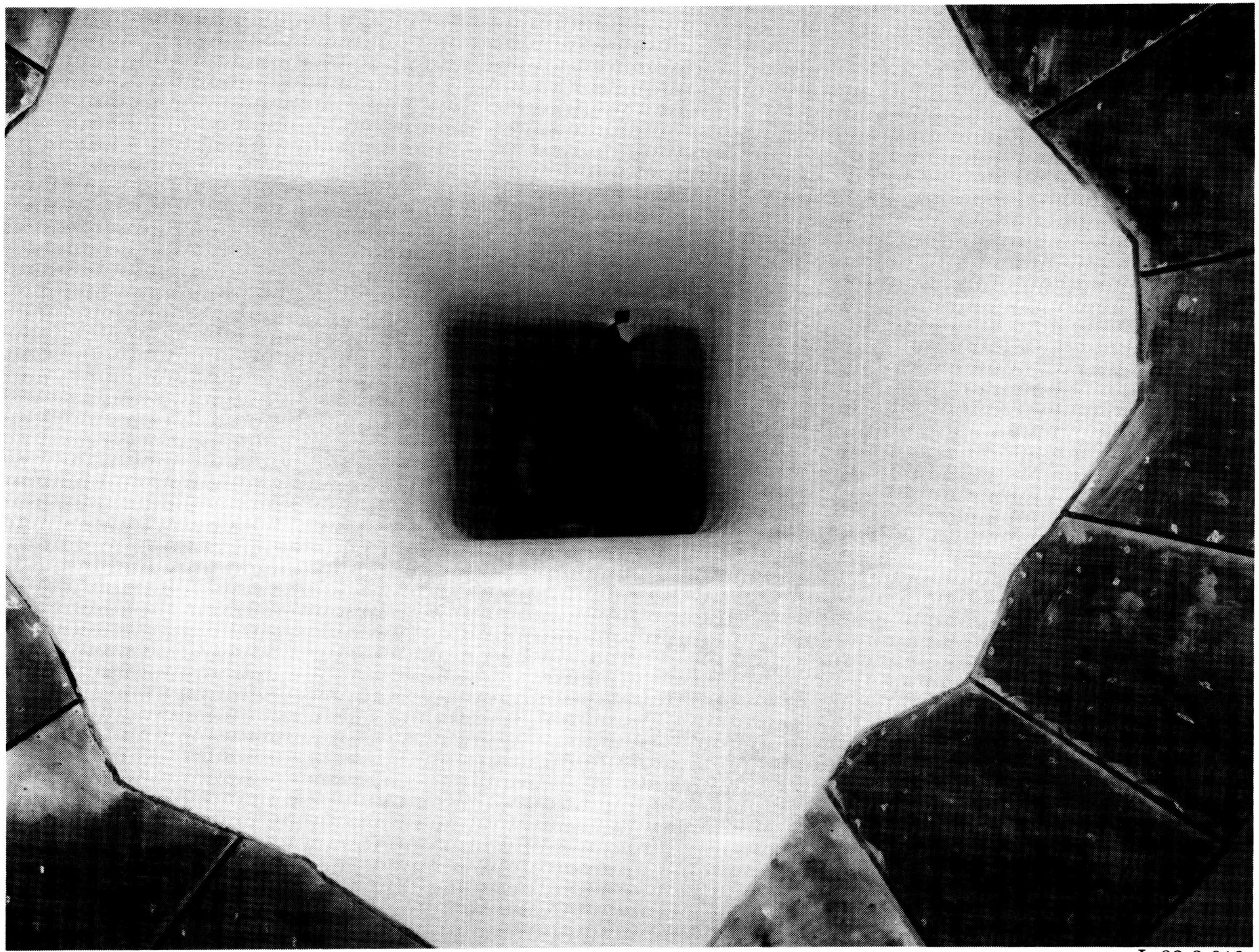
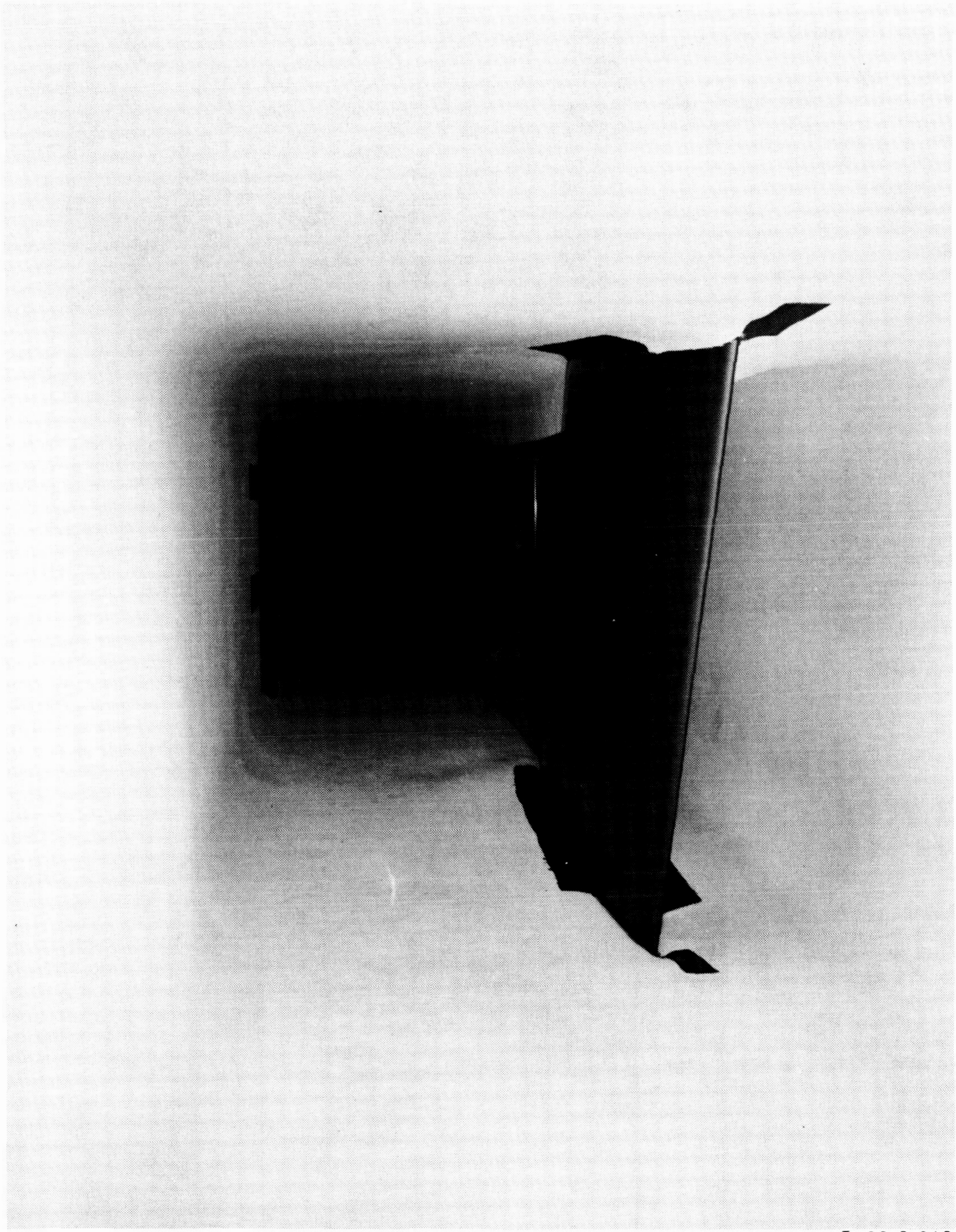


L-82-3,618

(a) View downstream from settling chamber of entrance cone and test section with LFC model installed.

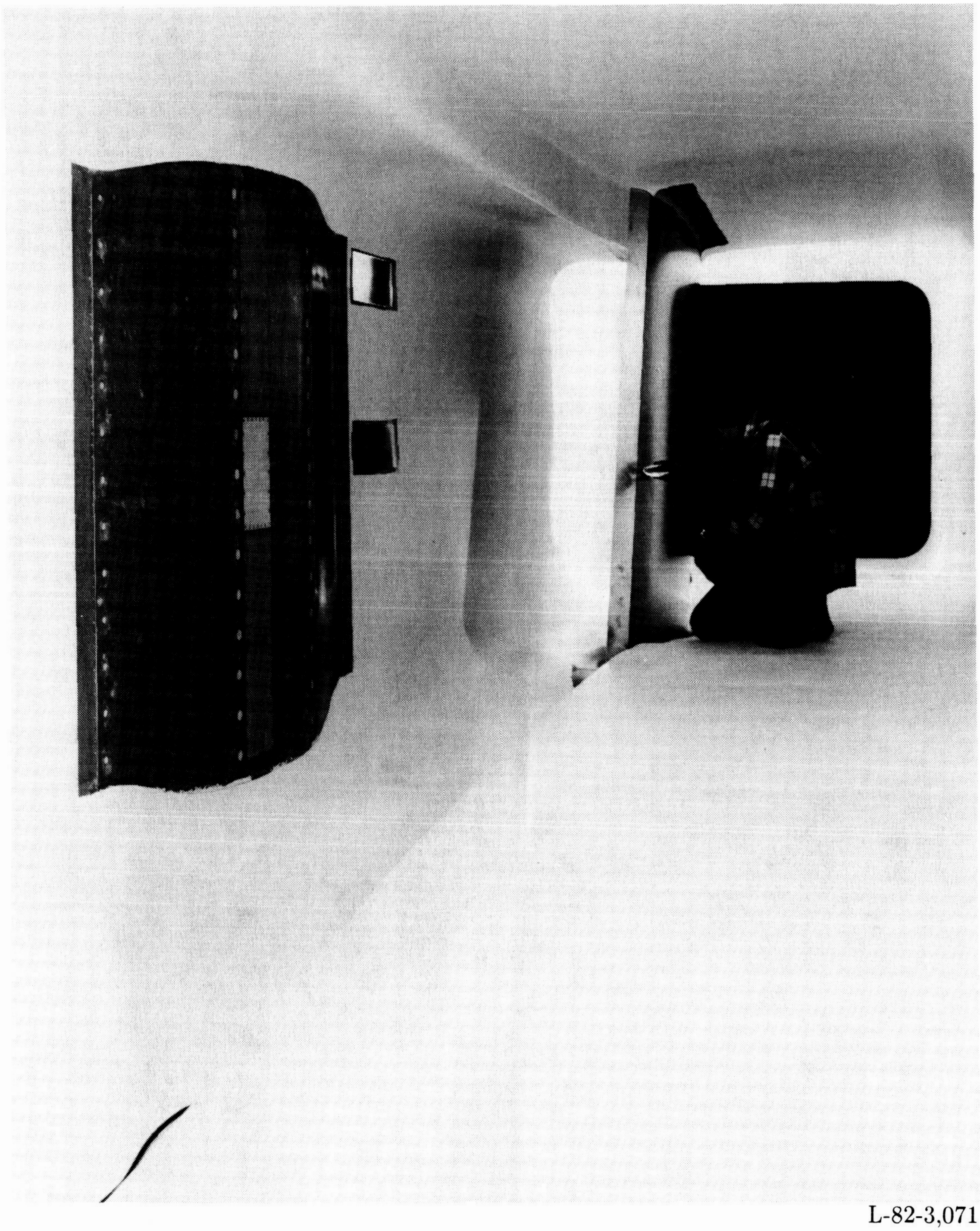
Figure 43. Completed test section liner.



L-82-3,619

(b) View downstream from forward region of test section.

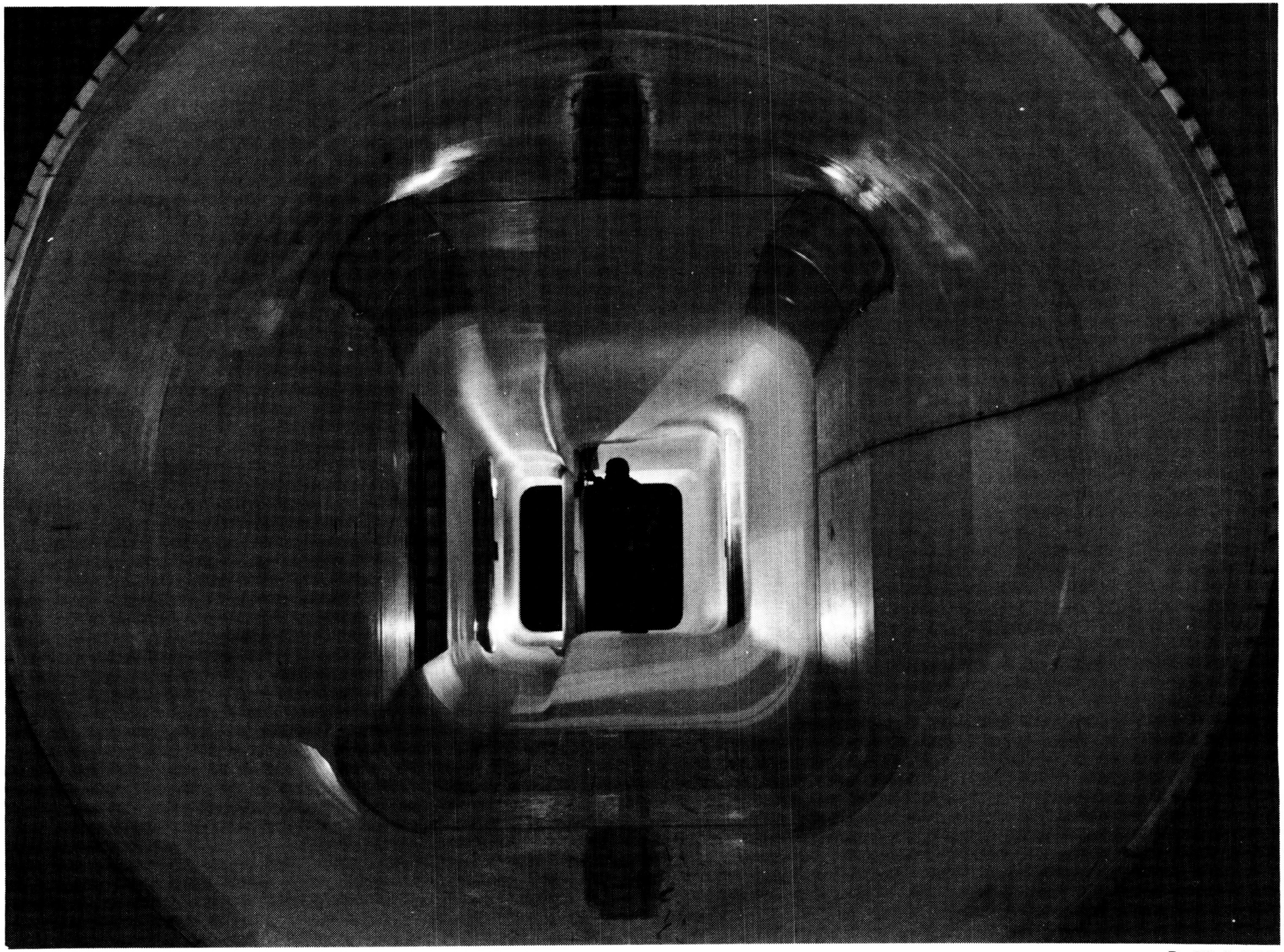
Figure 43. Continued.



L-82-3,071

(c) View upstream from diffuser of model and west wall choke plate.

Figure 43. Continued.



L-82-3,068

(d) View upstream from diffuser.

Figure 43. Concluded.

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Report Documentation Page

1. Report No. NASA TM-4032	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Modifications to the Langley 8-Foot Transonic Pressure Tunnel for the Laminar Flow Control Experiment		5. Report Date May 1988 6. Performing Organization Code
7. Author(s) Charles D. Harris and Cuyler W. Brooks, Jr.		8. Performing Organization Report No. L-16387
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225		10. Work Unit No. 505-60-31-03 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001		13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Modifications to the NASA Langley 8-Foot Transonic Pressure Tunnel in support of the Laminar Flow Control (LFC) Experiment included the installation of a honeycomb and five screens in the settling chamber upstream of the test section and a 54-ft-long test section liner that extended from the upstream end of the test section contraction region, through the test section, and into the diffuser. The honeycomb and screens were installed as permanent additions to the facility, and the liner was a temporary addition to be removed at the conclusion of the LFC Experiment. This report briefly describes these modifications.

17. Key Words (Suggested by Authors(s)) Laminar flow control Wind tunnels Facilities	18. Distribution Statement Unclassified—Unlimited Subject Category 09

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	121	A06

NASA FORM 1626 OCT 86 NASA-Langley, 1988

For sale by the National Technical Information Service, Springfield, Virginia 22161-2171